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Mineral Technology 17

DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, SECRETARY
BUREAU OF MINES
VAN. H. MANNING, DIRECTOR

SANDSTONE QUARRYING IN THE UNITED STATES

BY

OLIVER BOWLES

WASHINGTON
GOVERNMENT PRINTING OFFICE
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PREFACE.

In 1914 an agreement was entered into between the United States Geological Survey, the United States Bureau of Standards, and the Bureau of Mines for a cooperative study of the stone-quarrying industry of the country. According to this agreement the Geological Survey is to observe and report upon undeveloped outcrops, the Bureau of Mines to make a study of operating or partly developed quarries, and the Bureau of Standards to make all physical and chemical tests of samples submitted by the other bureaus involved. "Safety in Stone Quarrying," Bureau of Mines Technical Paper 111, 1915, and "The Technology of Marble Quarrying," Bureau of Mines Bulletin 106, 1916, were the first and second and the present bulletin on sandstone quarrying is the third of a proposed series of papers dealing with various phases of the industry.

The attractiveness of many types of sandstone for structural purposes is well known. Many people, however, may not know that ordinary building sandstone consists of upward of 90 per cent silica, which is the hardest and most durable of all common minerals, and that well-cemented sandstone may be classed as one of the most permanent of all structural materials. When it is realized that sandstone to the value of only about $1,800,000 is sold annually for building purposes in the United States, it becomes evident that the industry has not by any means reached a stage of development commensurate with what should be the requirements of a country that has largely passed the pioneer stage of development and has a population of about 100,000,000 people. The erection of structures combining both permanence and attractiveness should at this stage of our history be a national aim, and ideal conditions can be attained in a large measure by selecting for building purposes the finer grades of sandstone with which the country is so richly endowed.

It is the aim of this bulletin to point out in a general way the location of workable sandstone deposits in the United States, and to outline the most efficient and economical methods of quarrying and preparing the rock for structural and other purposes.

A feature of especial interest to quarrymen is a brief presentation of the distribution of serviceable sandstone by type and geologic age in every State of the Union.

During 1915 personal visits were made to 51 active sandstone quarries. As in the marble investigations, representative samples were shipped from the sandstone quarries to the Bureau of Standards for testing. The results of the tests will appear in due time.

Consideration of the operations and equipment connected with the quarrying of sandstone, which constitutes the major part of the report, includes a discussion of the various steps involved, from prospecting and stripping to removal of the blocks from the quarry pit, and their manufacture into marketable forms. Bluestone and ganister are types of sandstone that require different methods of quarrying from those employed with other sandstones, and therefore they are discussed under separate headings.

Mr. Bowles has not presumed to recommend new and untried methods except in a few instances. Rather, his aim is to present to all sandstone quarrymen a concise discussion of the methods and equipment at various sandstone quarries throughout the country, and the conditions under which certain types give the best results. A notable exception to this rule is, however, his expression of a conviction that under certain conditions tunneling methods, which have heretofore been employed on a small scale only, would be advantageous. The use of a balance car on inclined quarry floors, as employed in certain marble quarries, is also recommended.

The various phases of the problem of waste are considered, and the point is emphasized that great care should be exercised in eliminating waste, in view of the limited number of uses for which defective sandstone blocks may be employed. The great need of waste reduction is evidenced by the fact that in some sandstone quarries waste at the present time amounts to 75 per cent of the rock quarried.

The chief dangers to which sandstone quarrymen are exposed are pointed out, and means of reducing the number of casualties are considered.

It is confidently hoped that the material presented herein will tend to promote greater efficiency and safety in all phases of the sandstone-quarrying industry, and will also encourage increased activity in the production of sandstone for building.

Acknowledgment is made of the cordial cooperation of all sandstone quarrymen with whom the bureau's representative came in contact. Mr. H. E. Adams, of the Ohio Quarries Co., rendered especially helpful service.

C. L. Parsons,
Chief, Division of Mineral Technology.

SANDSTONE QUARRYING IN THE UNITED STATES.

By Oliver Bowles.

SANDSTONE IN GENERAL.

VARIETIES OF SANDSTONE.

The term "sandstone" is applied to a rock composed of mineral grains smaller than pebbles, cemented together more or less firmly.

"Conglomerate" is the name given to a rock composed of pebbles, or pebbles and bowlders, of various sizes cemented together. If the pebbles are large and well rounded the rock is sometimes called "pudding stone."

Although the term "sandstone" includes all varieties, certain specific terms are applied to types characterized by particular compositions, colors, or uses. "Quartzite" is a variety in which the individual grains are so firmly cemented together with quartz that the rock will fracture as easily through the grains as through the cement; "ferruginous sandstone" is one rich in iron as cementing material, or as grains, or both; "micaceous sandstone" is one in which mica is prominent; "arkose" is a feldspathic or granitic sandstone composed of angular grains; "calcareous sandstone" is one containing considerable calcium carbonate; and "argillaceous sandstone" is one containing considerable clay.

The term "flagstone" is used for a rock that splits readily into sheets suitable for flagging; "freestone" for rock than can be cut or carved readily, and with equal ease in all directions; and "ganister," in the United States, for sandstone suitable for the manufacture of refractories. Others are named from their characteristic colors such as "bluestone," "redstone," or "brownstone."

COMPOSITION OF SANDSTONE.

As a rule the majority, and in some samples nearly all, of the grains that form sandstone are of quartz. Rarely, a sandstone is found consisting of grains of limestone. Many of the quartzose sandstones contain grains of various minerals such as feldspar, gar-

net, magnetite, zircon, and mica. Muscovite or white mica is common in sandstone. Iron oxide, calcium or magnesium carbonates, and clay are other common accessory constituents. Calcareous sandstones are intermediate types between sandstone and limestone, and argillaceous sandstones are intermediate between sandstone and shale. The calcareous and argillaceous types are little quarried. In the table following are given some typical analyses of sandstones:

Some typical analyses of American sandstones.

Sample	I	II	III	IV	V	VI	VII	VIII
Silica	93.13	92.15	90.70	77.56	95.85	82.00	84.57	94.73
Alumina	3.86	3.85	5.00	10.75			5.90	.36
Ferrous oxide (Fe_2O_3)	.11	1.40	....		....	....		
Ferric oxide (FeO)	.54	.40	1.30	4.59	2.64	11.10	6.48	2.64
Calcium oxide (CaO)	.19	.50	.10	.34	.81	.98	....	.38
Magnesium oxide (MgO)	.25	.20	.20	1.22	.08	.81	.68	.36
Titanium oxide	....	....	.75	....	....	....	....	....
Potash	....	....	Trace	2.15	....	1.29	....	....
Soda	....	....	....	.90	....	1.06	....	....
Loss on ignition	1.43	1.70	1.70	[a] 2.59	.45	2.48	1.92	.83
	99.51	100.20	99.75	100.00	99.83	99.72	99.55	99.30

[a] Includes also undetermined matter and 0.09 per cent manganese oxide.

NOTES ON SAMPLES.

I. Light-gray sandstone, Berea, Ohio; analyst, N. W. Lord.
II. Sandstone, Cleveland Stone Co., Quarry No. 6, Amherst, Ohio; analyst, D. J. Demorest.
III. Sandstone, Fulton, Ohio; analyst, D. J. Demorest.
IV. Bluestone, Oxford, N. Y.; analyst, W. E. Gifford.
V. Salmon-red sandstone, Glencoe, Colo.[a]
VI. Sandstone, Rockville, Mo.[a]
VII. Sandstone, Stony Point, Mich.; analyst, F. W. Clarke.
VIII. Red sandstone, Portage Lake, Mich.[a]

The presence of alumina, together with potassium or sodium, or both, indicates that feldspars are probably present. Alumina without the alkalies indicates the presence of clay. A calcium or magnesium content indicates that the carbonates of calcium and magnesium form cementing material between the grains of sand, except where sufficient plagioclase, biotite, or hornblende are present in the rock to account for these constituents. Analyses V and VIII indicate the comparatively small percentage of iron oxides that can cause deep coloration.

PHYSICAL PROPERTIES OF QUARTZ.

Quartz forms the major part of most sandstones; hence a description of its physical properties is desirable. Chemically, quartz has the composition SiO_2, the pure mineral consisting of 46.7 per cent

[a] Quoted by G. P. Merrill, Stones for building and decoration. 3d ed., 1910, p. 516.

silica and 53.3 per cent oxygen. It is brittle and breaks with a conchoidal (shelly) fracture. Smooth and even cleavage planes are rarely seen. Its hardness is 7 in Mohs's scale, in which glass is about 5. Quartz is the only common glassy mineral that will scratch glass. Its specific gravity—that is, its weight as compared with the weight of an equal volume of water—is about 2.6. It is usually colorless or white, though when impurities are present it may have a variety of colors, as pink, smoky, or purple. Quartz is commonly found in crystal form, as hexagonal prisms and pyramids, though in sandstone it is usually in the form of irregular water-worn grains. It is the least soluble of all common minerals, being readily attacked only by hydrofluoric acid. It is an essential constituent of granite and related rocks, and when such rocks disintegrate the resistant quartz is least affected, and therefore remains as sand, which may later be consolidated into sandstone.

ORIGIN OF SANDSTONE.

Rocks at or near the surface of the earth are constantly undergoing disintegration by the weather and other agencies. The changes are both physical and chemical.

The physical changes include the action of frost, running water, waves, tides, and wind, which tend to break down and wear away exposed rocks. Extensive surfaces are thus presented to be attacked by various chemical agents, such as water, carbon dioxide, and oxygen, that tend to alter the original minerals of the rocks into forms that are stable under conditions prevalent at or near the surface of the earth. The minerals produced by such processes on granites and related rocks are quartz, iron oxides, clay, and also various hydrosilicates, the latter altering finally to iron oxide, and kaolin or related clay-like minerals.

The products of rock decay are carried away by streams and finally deposited in oceans or other large bodies of water. When the material transported by rivers reaches a large body of water the heavier pebbles are left near the shore, the coarse sand grains are carried farther, the fine sand grains still farther, and the clay may be transported far from the shore and deposited in deep water. By subsequent cementation, the pebbles will form conglomerates or "pudding stones" and the sands will form sandstones.

Water has the ability to sort and classify with a remarkable degree of refinement the material that it deposits. Thus grains of the same size are segregated into particular zones, accounting for the remarkable uniformity in grain size in many sandstone deposits of wide extent.

The formation of a pure quartzose sandstone may require several cycles of change like that recorded above. For example, the process

of disintegration may break up the granites or similar igneous rocks into small grains, but before the process of alteration of the constituent minerals into their most stable forms is completed, and before the materials have been thoroughly sorted by water, the fragments may be cemented together. The resulting rock would consist of grains of quartz, partly altered feldspars, and possibly mica and hornblende, together with certain other minerals formed by alteration of some of the original constituents. The grains of such a rock would probably be angular in shape, as water action sufficient to form well-rounded grains would at the same time wear away and separate from the sand all, or nearly all, of the feldspars, micas, and hornblende. Feldspathic, angular-grained sandstones like those described above are termed "arkose sandstones," or simply "arkose." The bluestones of Pennsylvania and New York described on subsequent pages, and also some of the Triassic brownstones, are of this type. It is evident that if the arkose is in turn disintegrated by surface weathering, the processes of alteration and wear will continue, and when the residium is again deposited and consolidated, the resulting rock will contain a larger percentage of silica and a lower percentage of other constituents than the arkose from which it has been formed. It is, therefore, by such repetitions of this process of disintegration and decay, or by a single process of long duration, that the pure sandstones containing 95 to 99 per cent silica are formed.

The grains of the relatively pure quartzose sandstones are usually well rounded owing to the wear that they underwent when beaten by waves or rolled by streams or currents. Wind action also plays an important rôle in the rounding of sand grains and in their transportation and deposition. Sandstones that have been modified by wind action show perfectly rounded grains of small size and characteristic curves in the stratification, while cross bedding is common.

SIZE AND SHAPE OF GRAIN.

Sandstones vary widely in size of grain. The grains of some are so fine that the rock may be used to make razor hones, as for example the sandstone quarried near McDermott, Ohio. The size of grain of a typical sandstone from northern Ohio may be judged from the results of sieve tests of a sample taken from a quarry near Amherst. Practically all the grains pass through a sieve having 40 meshes to the linear inch, four-fifths pass through a 60-mesh sieve, two-thirds through 80-mesh, one-third through 100-mesh, and one-fifth through 120-mesh. Several tests of the Kettle River, Minn., sandstone showed that 70 per cent passes through 40-mesh, and 30 per cent is between 20 and 40 mesh.

The coarser angular-grained sandstones are termed "sandstone grits." The term grit is used in a commercial sense with a somewhat different meaning, however, a commercial grit being a sandstone well adapted for abrasive purposes, and not necessarily of coarse grain. For example, the commercial Berea grit of northern Ohio is in places very fine grained.

In some sandstones the grains are well rounded, whereas in others they may be rather angular. This difference depends on the amount of wear that the grains have undergone before consolidation.

When coarse pebbles are cemented together the rock is termed "conglomerate." The Roxbury pudding stone occurring in and near Boston is a good example of a conglomerate. It consists chiefly of well-rounded pebbles, some of which are several inches in diameter, the spaces between the pebbles being filled with smaller pebbles, sand grains, and cementing material. The term breccia is applied to a rock composed of cemented angular fragments.

UNIFORMITY OF GRAIN SIZE.

In some sandstones the size of the grains is closely uniform throughout large masses; in others the size is variable. The grain size is usually nearly uniform in a given bed, the most marked variations being observed in passing from one bed to another. This is due to the fact that the sand of an individual bed has been deposited over a wide area within a limited time, and probably under uniform or nearly uniform conditions. During the time that has elapsed between the deposition of one bed and the subsequent bed the conditions may have materially changed; in fact, the separation of a sandstone ledge into different beds is an indication of changing conditions. Uniformity of grain size is desirable in the better grades of commercial sandstones.

CEMENTATION.

As sandstones are merely consolidated sands, it is highly important to know the nature of the cementation that has taken place, the kinds and qualities of the cementing materials, and the degree of adhesion between the grains. The common cements are limonite, clay, calcite, and quartz. Combinations of different cements may occur in the same stone.

The ferruginous or iron cement consists in most places of limonite ($2Fe_2O_33H_2O$) with or without other iron compounds. Sandstones cemented by iron oxides afford a great variety of colors, such as yellow, brown, buff, red, and occasionally greenish. Commonly, the ferrous iron compounds, those having a comparatively low oxygen content, are present, and such oxides on exposure to the air may

change into ferric compounds—those having a higher oxygen content. The latter are red, yellow, or brown, whereas the former may be of much lighter shades, and consequently the process of oxidation may materially change the color of the rock. If the oxides are unequally distributed, undesirable streaks or spots may be formed by oxidation, but if they are uniformly distributed throughout the stone, the change in color may be uniform and may not detract from the appearance.

Clay is a soft cementing material, and may crumble easily. Furthermore, it absorbs water readily, and exposure to frost may result in a rapid crumbling away of the sand grains. Clay is therefore to be regarded as an inferior cement.

Calcite ($CaCO_3$) can be recognized in sandstone by the effervescence that results when a drop of hydrochloric acid is placed on the surface of the rock. Calcite is soluble in water containing carbon dioxide, and as rain water contains more or less carbon dioxide dissolved from the atmosphere, calcite cements are liable to be dissolved where the rock is exposed to weathering. As the cement disappears the surface grains will fall out, a new surface will be presented to the agents of solution, and thus the process of disintegration will continue.

Quartz or silica (SiO_2) is a common cement in sandstones. It is hard, impervious, and the least soluble in ordinary atmospheric agencies of all common minerals. Consequently, sandstones with a firm siliceous cement are durable.

All stages of cementation are to be found in nature from the incoherent sandstones, which may be crumbled in the hands, to those so indurated that all trace of their original granular form is lost. Sands have many uses, and sandstones are in some places pulverized back to their original sandy condition for various purposes. For structural uses, grindstones, etc., a certain degree of cohesion is, however, necessary. The most indurated types are those that have siliceous cement. The cementing silica may be introduced independent of the original grains or it may grow about the original grains, forming larger crystals. This is known as "secondary enlargement." It tends to develop pyramidal crystal faces, and at intermediate stages of cementation innumerable brilliantly reflecting faces will be in evidence. This is characteristic of the Kettle River sandstone of Minnesota. The addition of siliceous cement may continue to a point where all trace of granulation is lost, the rock having the appearance of massive quartz. Such rocks are termed "quartzites." Quartzites are also formed by a general recrystallization of sandstones due to regional metamorphism. A quartzite may be defined as a rock consisting of sand grains cemented together so firmly

that when it is broken the fracture passes through the grains as readily as through the cement.

Leith and Mead[a] have pointed out that quartz is to be regarded as the permanent cement of sand, the carbonates and iron oxides being temporary cements in the sandstone stage of development. On this account the older sands are more likely to be cemented into quartzites than the younger ones, because the process of cementation has covered a longer period of time. Thus in early pre-Cambrian deposits quartzites are more common than sandstones. It must be noted, however, that there are sands and sandstones as old as Paleozoic or late pre-Cambrian, and quartzites as late as Tertiary. Thus time is not the only element upon which cementation depends; conditions of pressure, water circulation, and the nature of the solutions may have a controlling influence. As pointed out on subsequent pages, some sandstones harden considerably within a short time after quarrying.

In some deposits extreme induration may have taken place in certain spots only, forming the so-called "hard-heads"; in others some spots are less firmly cemented than the main mass. Such nonuniform cementation is unfavorable for quarrying and usually results in abnormal waste.

On account of the different varieties of cements present and the great range of induration possible, sandstones are the most variable in hardness of all common rocks. In this connection it is necessary to define what is meant by the hardness of a sandstone. The individual quartz grains of a sandstone that may be crumbled in the hand are as hard as the fragments of a quartzite. Hardness, therefore, does not refer to the resistance to abrasion that the individual grains possess, but rather to the degree of adhesion between the individual grains. Hardness is in this sense synonymous with workability.

COLOR.

The color of a sandstone is governed by its composition. The more important coloring ingredients are the iron compounds. A white or other light color that persists after exposure to oxidation indicates their absence. Brown, reddish, or yellowish colors denote the presence of ferric oxides, the more common forms being hematite (Fe_2O_3) giving a red color or limonite ($2Fe_2O_33H_2O$) giving yellow to brown colors. Gray or bluish shades may be due to the presence of iron carbonate or grains of hornblende or chlorite. Black carbonaceous matter is rarely disseminated uniformly throughout the

[a] Leith, C. K., and Mead, W. J., Metamorphic geology, 1915, pp. 122–123.

rock mass, and therefore has little or no effect on the color of the rock as a whole, but occurs rather in the form of black streaks or spots.

Permanence of color is a desirable quality in structural stone, although a uniform change in color may not detract from its appearance. The deeper shades of red, brown, or buff are usually permanent, because they are due to the presence of the stable iron oxides. Blue or gray sandstones quarried from the lower ledges of a deposit are, however, commonly subject to change of color. If ferrous sulphides or carbonates are present, weathering tends to produce a buff or reddish color by oxidation of the ferrous compounds to more stable forms. On this account the upper beds of some sandstone deposits may be buff, whereas the lower beds are gray or blue-gray, the latter being the unstable colors.

Although uniformity in the distribution of color is to be desired for most structural purposes, rocks having streaks or bands of color may in some places give very attractive effects for interior decoration. Blocks that would at one time have been thrown on the waste heap on account of nonuniformity of color distribution are now being utilized to some extent for ornamental building.

POROSITY.

The porosity or percentage of pore space in sandstones is in general greater than in most other rocks. It depends to a large extent on the condition of cementation. Most friable stones with little cementing material are very porous, whereas the highly indurated quartzites may have almost as low a percentage of pore space as granites. Various determinations made by Buckley and Parks[a] show a range in porosity of sandstones varying from 2 to over 15 per cent. A high porosity, especially if the pores are of small size, is undesirable in sandstones exposed to the weather in freezing climates, as water may freeze in the pores and thus cause disintegration of the rock. Porosity is commonly expressed as "ratio of absorption," which is the weight of water in the pores divided by the weight of the dry stone. This is multiplied by 100 to express it as a percentage. A high porosity does not necessarily mean a high ratio of absorption, as the latter depends also on permeability, by which is meant the ease with which the water can pass from pore to pore. Usually, however, rocks that have a high porosity have also a high ratio of absorption.

SPECIFIC GRAVITY AND WEIGHT PER CUBIC FOOT.

The specific gravity of a substance is its weight as compared with the weight of an equal volume of water. The apparent specific

[a] Parks, W. A., Report on the building and ornamental stones of Canada, vol. 1, 1912, pp. 61.

gravity of sandstone may differ considerably from the actual specific gravity of the material of which it is composed. The former is influenced by the percentage of porosity, whereas the latter is determined after pore space has been eliminated. In rocks with high porosity, therefore, the apparent specific gravity is much lower than the actual figure for the constituent minerals. The apparent specific gravity multiplied by 62.5, which is the weight in pounds of a cubic foot of water, gives the weight of the dry rock per cubic foot. A low specific gravity usually indicates a high porosity, and therefore a high ratio of absorption. The following figures, obtained from actual tests, illustrate the interdependence of specific gravity and ratio of absorption:

Friable sandstone: Specific gravity, 1.825; weight per cubic foot, 113.1 pounds; ratio of absorption, 1:8.

Quartzite: Specific gravity, 2.729; weight per cubic foot, 170.6 pounds; ratio of absorption, 1:366.

CRUSHING STRENGTH.

The crushing strength of sandstones differs widely in different deposits. The many recorded tests show crushing strengths of 3,000 to 27,000 pounds per square inch. As a rule the crushing strength is somewhat higher across the bed than parallel with the bed. The strength depends greatly upon the degree of cementation of the grains. Sandstones that are poorly cemented are weak, whereas the more indurated types are much stronger. Rocks that are poorly cemented usually have a high ratio of absorption, and therefore the absorption ratio has a direct bearing on strength. A comparison of the figures given in the physical tests recorded by Merrill[a] shows the remarkable interdependence of strength and ratio of absorption, a weak rock having in almost every case a high absorption, and a strong rock a low absorption.

Sandstones that are in other respects suitable for building are usually strong enough for all ordinary uses, owing to the fact that a poorly cemented rock is generally condemned on account of friability before it is condemned on account of low crushing strength.

STRUCTURAL FEATURES OF SANDSTONES.

BEDS.

As described in the discussion of origin, sandstones are laid down originally as sands in beds or layers. In some deposits there are open planes of separation at intervals of several inches or several feet. Such planes are usually due to marked changes in the process

[a] Merrill, G. P., Stones for building and decoration 3d ed., 1903, pp. 504-507.

of sedimentation. Commonly a layer of shale or clay material intervenes between the sandstone beds. In other deposits, possibly on account of a pause in, and subsequent resumption of the process of deposition, the later bed may show no change in composition from the earlier, but there may be merely a lack of coherence between the beds, which are separated only by a smooth surface. Some open bedding planes are flat and smooth; others are wavy and uneven. In some deposits open-bed seams are continuous over wide areas; other seams when traced for short distances may be found to close up. Typical open-bedded sandstones are those of Berea and McDermott, Ohio; Farmer, Ky.; Potsdam, N. Y.; and Kettle River, Minn. The beds may be horizontal or tilted. As sands are deposited near shore, where the sea floor commonly inclines at a low angle, sandstone beds may exhibit a moderate dip even though undisturbed; others are tilted at various angles by earth movements.

Other sandstone deposits are unbroken throughout a vertical extent of many feet, or may have scattered horizontal breaks that are continuous for short distances only. When such deposits were formed, the deposition was clearly uninterrupted, permitting a subsequent uniform adhesion of grains at all points. The extensive deposits near Amherst, Ohio, are of this type.

What is known as crossbedding is common in sandstone. In such stones certain of the lines that mark planes of sedimentation cross the chief beds obliquely. Swirling eddies or currents in the water in which the sand was originally deposited probably account for such an arrangement. Ripple marks and worm borings are also common.

JOINTS.

Joints are presumed to originate mainly through compressional or torsional earth strains. A more complete discussion of their origin may be found in Bureau of Mines Bulletin 106.[a] Their economic importance relates chiefly to their arrangement and proximity to each other. They are usually perpendicular to the bedding in flat-lying deposits, and hence are vertical or nearly so. Where beds are steeply inclined the joints are less commonly perpendicular to the beds, meeting them rather at more or less oblique angles. Figure 1 represents the position of beds and joints in a quarry near New Haven, Conn.

Usually joints occur in two or more systems, the joints of each system being approximately parallel with each other. Joints greatly facilitate the process of quarrying where they occur in two vertical systems at right angles, and are 10 to 40 feet apart.

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[a] Bowles, Oliver, Technology of marble quarrying: Bull. 106, Bureau of Mines, 1915, pp. 23–26.

In some deposits joints in one parallel set may be much more closely spaced than those of the second set. At Medina, N. Y., the joints of one system are spaced 10 to 40 feet apart, with an occasional intersecting joint. In other regions joints lack a well-defined parallelism; they may meet at sharp angles or may be curved or irregular. Near Springfield, Mass., and Hummelstown, Pa., joints present a less systematic arrangement than in some other deposits.

CUTTERS.

The term "cutter" is applied to a closed or inconspicuous joint, though with some quarrymen the term covers all types of joints. They are known also as "blind seams" or "closed seams." They may occur at wide intervals or in parallel groups of closely spaced cutters separated by masses of rock containing comparatively few

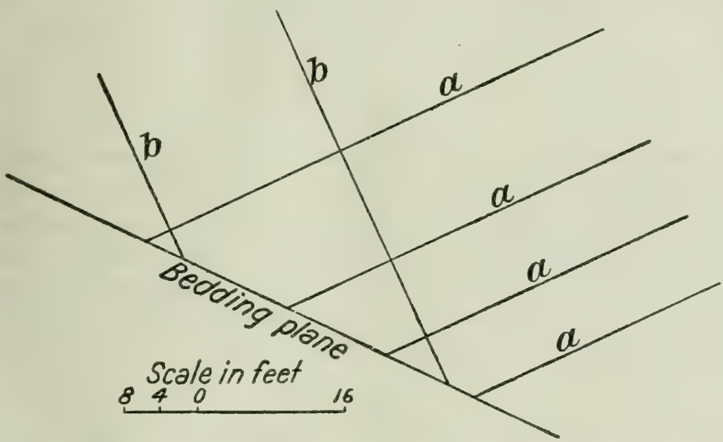

Figure 1.—Position of beds and joints in quarry near New Haven, Conn. Lines *a* and *b* represent two systems of joints, each meeting the bedding plane obliquely.

of them. Cutters may continue for long distances or may have a length of a few feet only. In some places they are hard to recognize, and in others they may appear as yellow or buff streaks due to oxidation where the atmosphere has entered the minute cracks. Occasionally they are completely sealed by deposited silica and may be strong, but usually cutters are planes of weakness. They are responsible for much of the waste in many quarries.

RIFT.

Rift is the plane of easiest splitting in a sandstone, and almost without exception the rift is parallel to the bedding. It is a variable property, some beds splitting with the utmost ease, whereas in others the rift is so poor that the rock splits in other directions almost as

easily as it does parallel to the bed. As a rule the maximum grain cohesion in a mass of sandstone is parallel with the bedding and the minimum cohesion is perpendicular to the beds. The difference in grain cohesion between these two directions is a measure of the rift. Thus, if there is no difference, the rock splits with equal ease across the bed and parallel with the bed, and there is no rift. If, on the other hand, the grain cohesion parallel with the bedding is three times as great as across the bed, the rift is pronounced.

Rift seemingly depends mainly on grain orientation. The presence of flaky minerals, as mica and clay, may increase the rift. During the process of deposition there is a tendency for such grains to come to rest in a horizontal position and thus parallel to the bedding plane. In like manner all the mineral grains tend to have their long axes parallel to the bedding plane, and such parallelism has a marked influence upon the ease of splitting.

Various beds in the same quarry may show great variation in rift. Thus in the Amherst quarries "split-rock" beds have excellent rift. The split surface may be as smooth and uniform as the sawn surface. In the "cross-grained" rock cross bedding is in evidence. At various points the bedding slants at abrupt angles to the general bedding plane. Splitting of such rock is difficult and uncertain. The "spider web" represents another form of cross bedding on a small scale, which is complicated by intricate interlacing of fine bedding planes. Splitting is difficult in this rock and the split surface may be uneven. The "liver rock" presents a massive structure without any indication of bedding, and consequently is lacking in rift.

REEDS.

The rift may not be the same in all parts of the same bed; that is, the rock may split much more easily along certain planes than along others. This may be due to a change in sedimentation, such as the deposition of a thin layer of foreign material, as clay, to which the sand grains above and below do not adhere readily, as in the formation of open bedding planes. Again, it may be due to a pause in the process of deposition with a smoothing over of the surface and a filling up of the irregularities that are essential to a condition of relatively high cohesion perpendicular to the bedding plane. It may also be due to parallelism of grain orientation in certain zones. Such planes along which the rock tends to split with greater ease than in intermediate planes are termed "reeds." They are characteristic of many bluestone deposits. In the quartzites near West Haven, Pa., reeds have been observed that split easily along certain fine white lines and with difficulty in intermediate positions.

RUN.

The term "run" or "breaking way" is applied to a second direction of easy splitting that is less pronounced than rift. The term "grain" is also used, though with some quarrymen "grain" is synonymous with rift. The direction of run is usually perpendicular to the rift, and therefore in flat-lying beds it is in some vertical plane. It may maintain a uniform compass direction over a wide area. Bownocker[a] states that from Berea to Berlin Heights, Ohio, the run is nearly east and west; that is, parallel to the old shore line. The cause of run is obscure, though probably it is due to mineral orientation. It is possible that prevailing ocean currents at the time of deposition had a tendency to hold a majority of the mineral grains with their long axes parallel to a particular compass direction. In many quarries a distinct run is recognizable and has a marked influence on quarry methods. In other quarries it is absent or so indefinite as to exert no apparent influence on quarry processes.

QUARRY WATER.

Most sandstone in the undisturbed quarry ledge contains water filling the intergranular spaces. The pores of rocks may be divided into two classes—capillary, or larger, and subcapillary. The former group includes openings more than 0.00002 centimeter in diameter and the latter those of smaller size. The pores of capillary size or larger contain mainly "water of saturation," which passes off readily when the rock is exposed to a dry atmosphere. The subcapillary pores contain what is termed "water of imbibition," which is released with greater difficulty. The water that fills the pore spaces is called "quarry water." Quarry water, especially the water of imbibition, carries considerable mineral matter in solution, and when the water evaporates the mineral matter is deposited as a cement between the grains, thus making the rock appreciably harder. As most of the water travels from within outward and evaporates near the surface, a sort of casehardening results. Subsequent wetting of the stone will not materially soften it when once the quarry water has evaporated. Frequently, therefore, freshly quarried rock may be cut easily, but when the quarry water has dried out the stone may be difficult to work. The desirability of shaping sandstone into permanent forms soon after quarrying is obvious. By so doing the rock may be easily worked, and the subsequent drying out of quarry water gives the finished blocks an exceptionally hard surface.

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[a] Bownocker, J. A., Building stones of Ohio: State Geol. Survey, ser. 4, Bull. 18, 1915, p. 111.

EFFECT OF FREEZING ON SANDSTONE.

The freezing of sandstone blocks before the quarry water is evaporated usually results in their disintegration. On this account sandstone quarrying is usually suspended during the late fall and winter. Subsequent to quarrying, sufficient time must elapse for the quarry water to evaporate before freezing weather arrives. The time required for drying out of quarry water depends on the size of the pores and the size of the blocks quarried. If the pore spaces are mainly subcapillary a longer period is required than where they are of larger size. Also large blocks require a longer drying period than small ones. There seems to be a certain dependence also on the rift or bedding of the rock. In a " split rock," one that parts easily along bedding planes, the water finds an easy course parallel with the bedding, and escapes more readily than it does from a " liver rock," one that has no rift. In certain quarries beds of " liver rock " at the quarry face may be damaged by frost, whereas adjacent split-rock beds are undamaged, showing that the quarry water has escaped from the split rock, although it has remained in the "liver rock."

The fact that quarry water travels readily parallel with the rift is recognized by many quarrymen. It has been found that if an unseasoned block of rock with good rift is so placed that all its edges are exposed, severe frost will result in disintegration. If, however, the block is so placed that it rests on one edge, and this edge is buried in sand, no damage is likely to result. The most logical explanation of this phenomenon seems to be that in the former case the entire edge surface is first frozen, leaving no ready means of escape for the quarry water, and as frost penetrates deeper the expansion resulting from the transformation into ice of water in the pores fractures the rock mass. In the latter case the one edge that is not frozen leaves a way of escape for the quarry water as the frost penetrates from the other edges, and no destructive fracturing results.

In some deposits the damaging effects of frost are not apparent in the quarry ledge; in others the rock adjacent to exposed surfaces may be severely damaged. Where there is danger of destructive frost effects the quarry floor and face must be protected in some way during the winter months. In some places quarry waste is scattered over the floor and corn stalks are employed to protect the face. Other quarries are protected effectually by flooding with water.

THE USES OF SANDSTONE.

The various uses for which quarried sandstone may be employed are outlined below.

USE IN BUILDINGS.

Sandstone is used widely for both exterior and interior building. Its homogeneity of composition and resistance to the solvent action of rain water makes it especially useful for exterior work. It may be sawed or cut for building blocks either as even-course stone or broken ashlar; also for steps, caps, sills, water tables, coping, etc. It may be used for entire structures or for the trimming of structures made chiefly of brick or other material. For interior uses the more attractive types are in demand, those that have a color banding being employed by some architects. Sandstones that are fine-grained and nonabsorptive may be used for lavatories. Many sandstones are well adapted for carving, and attractive designs carved from sandstone are to be seen in many buildings. Some sandstones, especially bluestone, are occasionally employed for floor tile.

For rougher and less ornamental buildings, concrete has lately been used extensively, and has therefore greatly limited the use of sandstone for such construction. Heavy blocks of sandstone or quartzite were once used extensively in bridges, and are yet used considerably for this purpose. The lower grades of sandstone are used for rubble or cellar stone. The term "rubble" is applied to stones of various sizes, each of which has one good face; the term "cellar stone" includes irregular small fragments also. Such stones are used chiefly for foundations of houses or other structures. Retaining walls are commonly built of rubble, though sometimes the better grades of cut stone are used. Large fragments containing many imperfections may be used as riprap for breakwaters or for protecting river banks.

As quartz, the chief constituent of sandstone, is the most resistant to weathering of all common minerals, a well-cemented sandstone is among the most durable of all building stones; but sandstone has not by any means attained such extended use in the United States as its superior quality justifies.

USE FOR GRINDSTONES.

Sandstones, the grains of which are of proper size, shape, and uniformity, and are cemented in such a manner as to grind steel readily and at the same time wear away with sufficient rapidity to prevent glazing of the surface, are used to make grindstones. In several quarries, especially those in Ohio, grindstones are manufactured in various sizes up to 7 feet 6 inches in diameter. In quarries of the finer-grained sandstones, smaller pieces may be utilized to make small grindstones for cutlery or scissor grinding, or for making hones or whetstones.

The manufacture of pulp stones for grinding wood pulp, used in making paper, is of importance at some points on the upper Ohio River.

USE FOR PAVING STONES.

The manufacture of paving blocks is an important industry in many States. Sandstones suitable for paving must be well adapted for resisting abrasion. Only those in which the grains are firmly cemented together with siliceous cement; that is, the varieties known as quartzites, or sandstones which approach the quartzites in condition of cementation, may be used. Sandstones that have a good rift (easy bed splitting) and a good run (a second direction of easy splitting perpendicular to the bed) may be trimmed most readily, and therefore are a profitable source of paving stones.

Sandstones with moderate cementation are, by some authorities, preferred to granite for paving, on account of the fact that they present a gritty surface, and also because they wear down at about the same rate as the cementing material in the cracks, and thus maintain a level surface, whereas granite blocks become smooth and rounded.

USE FOR CURBING.

Curbstones may be of much softer material than paving stones, and although manufactured extensively in many quarries where paving stones are produced, they are also manufactured in large quantities in quarries where grindstones or building blocks are made. In the case of easy-splitting sandstone, curbing may be split out and hand trimmed at the quarry, while the more massive rocks are sawed into curbing.

USE FOR FLAGGING.

Sandstone may be sawed into thin slabs for making sidewalks. Rock for sidewalks must have adequate strength, must be hard enough to resist the abrasion of the feet of pedestrians, and must be reasonably free of impurities that give rusty spots or other stains when exposed to the weather. Bluestone is used extensively for walks, and has the advantage over most sandstones in that the reeds permit splitting into thin and uniform slabs of large size, thus saving the expense of sawing.

USE FOR GRAVE VAULTS.

The fine-grained, uniform sandstones of southern Ohio are used extensively for the manufacture of grave vaults. Each vault consists of six slabs of stone, two sides, two ends, bottom and cover. They are sawed 2 inches thick and are sand rubbed.

USES OF CRUSHED SANDSTONE.

USE AS AGGREGATE IN CONCRETE.

Sandstone is used to some extent for concrete mixtures, but only the harder types are suitable. This is due partly to the fact that the softer types are weak and partly because the crushing of soft sandstone results in a large proportion, possibly one-quarter to one-third, of the mass crumbling away as sand. Crushed sandstone for concrete must compete with crushed limestone, trap, and granite, and also with gravel, and as a consequence its use is limited to certain localities where it is of excellent quality or where it is more accessible than other types of crushed rock. Quartzites supply crushed rock of good quality. Although they are extremely hard, they are brittle and therefore not as difficult to crush as might be expected. Crushed bluestone also gives good service in concrete mixtures.

USE ON ROADS.

Most sandstones are too poor in cementing material to be useful for road surfaces, although certain quartzites are known to give good road surfaces for heavy traffic if the crushed stone is rolled wet. Some impure sandstones with considerable clay content have sufficient binding to make them serviceable for the finishing layer of roads or streets.

One Pennsylvania company manufactures a mixture of asphalt and crushed quartzite, and sells it under the trade name of "ameisite" for surfacing roads and streets.

Crushed sandstone gives satisfactory service for road bases, as it provides good drainage. It is also used in the construction of concrete road-bases.

The sand screenings from crushed stone may be utilized for mortar and concrete.

USE IN MAKING GLASS SAND.

Very pure sandstones and quartzites are crushed to make glass and pottery. Small percentages of impurities may be removed by washing. In one glass-sand plant visited the rock is crushed and ground and is then washed with water six times. The necessary purity is indicated by the following analysis of glass sand ready for the market:

Analysis of commercial glass sand.

Constituent.	Per cent.
Silica	99.85
Alumina	0.14
Iron oxide	0.012
Lime	Trace.

Inferior grades of sandstone are crushed for use on locomotives for sanding the tracks to prevent slipping of the wheels.

USE AS GANISTER.

Quartzites containing only a small percentage of impurities may be crushed and ground for the manufacture of silica brick or other refractories. Such rock is termed "ganister" in the United States. Coke ovens and furnaces of various types require silica brick for linings, and consequently there is a good demand for high-grade ganister.

MISCELLANEOUS USES.

Sandstones that are fine-grained, dense, and impervious may be cut into thin slabs and used for constructing laundry tubs and similar plumbing fixtures. Few sandstones are suitable for this purpose. Slabs of sandstone are used also for electric switchboards and billiard tables. Sandstone that splits satisfactorily is sometimes used to make fence posts. Cubical blocks may serve as footings or underpinnings for posts under heavy structures. Irregular masses are sold to fishermen to anchor nets. A limited amount of sandstone is used for monuments, though marble and granite are used much more widely for this purpose.

PROSPECTING FOR SANDSTONE.

GENERAL CONDITIONS.

Before opening a sandstone quarry, careful prospecting should be done to ascertain the quality of the rock. Color, uniformity of texture, size of grain, impurities present, and the size of blocks available should be determined as exactly as possible in order that a definite idea may be gained of the possible uses for which the stone may be employed. The probable demand for stone of the quality available must be carefully considered. The nearness of the market, availability of transportation lines, and freight rates are factors on which success or failure may depend.

DEGREE OF INDURATION.

As pointed out in the discussion of physical properties of sandstone, the degree of induration or hardness of the stone is governed by the condition of cementation of the individual grains. The prospector must study two features of the condition of induration—first, the effect of the hardness on the uses for which the stone may be employed, and second, the effect of hardness on quarry methods, quarry machinery, and possible rate of rock removal. For example,

a highly indurated sandstone can not be channeled but must be blasted out, with a probable high percentage of waste by shattering, whereas a soft sandstone may be channeled in cubical blocks, with a much smaller proportion of waste. The prospector must also remember that quarrying is much slower in a hard rock than in a soft one, and that accordingly the cost of production will be higher per cubic foot of the harder rock.

ROCK STRUCTURES TO BE OBSERVED.

Rock structures that may assist quarrying or that may have a detrimental effect must be carefully noted. The most important of these structures are joints. Their arrangement, distance apart, regularity, and attitude (whether vertical or inclined) should be determined carefully, as such factors are of great importance in laying out the direction of quarry walls. A method by which the most complete information may be obtained is to make a map, on which all the joints are drawn accurately to scale. From such a map one can determine the probable size of blocks available, the approximate proportion of waste, and the direction in which the quarry walls should run in order to give the minimum waste. The prevalence of irregular or closely spaced joints should be carefully noted, as their tendency is to increase the proportion of waste material.

IMPERFECTIONS TO BE NOTED.

All imperfections of texture or composition as they appear on the outcrop surface should be carefully noted. The more important imperfections are variations in texture, variations in hardness, as, for example, the presence of the so-called "hard heads," and variations in color, such as streaks or stains. If observations are made on a fresh surface, a careful search should be made for minerals such as iron sulphides, which upon exposure to the weather may cause stains.

SUPPLY OF STONE AVAILABLE.

Before involving himself in heavy expense for equipment, the prospective quarryman should be sure that he has a supply of available stone commensurate with the magnitude of his proposed operations. A mere assumption that stone of the quality observed in any one spot will continue over wide areas or to great depths is untenable. Such assumptions unsupported by actual investigation of the facts have led many companies to bankruptcy. Sandstone deposits are uncertain, as in short distances abrupt changes may take place both as to quality and supply available.

OBSERVATION OF OUTCROPS.

Superficial observation of sandstone may be made on outcrops, or trenching may be done to remove overburden. A study of the horizontal surface of flat-lying beds affords no knowledge of the depth of available stone. A much greater variation in the quality of sandstone is usually found in passing from one bed to another than is found in different parts of the same bed. On this account, an outcrop which exposes a cross section of a number of beds is most valuable for purposes of observation. It indicates the quality of the stone at various depths, and enables one to judge the probable supply more accurately than when observation of one level only is possible.

By observation of a weathered surface, one can judge the effect of weathering agencies on the rock. If any of the rock constituents cause stains by weathering, this fact will generally be in evidence, though it is possible that the weathering process has been so severe that the impurities which might cause stains have been entirely leached out and removed. Another valuable fact is that a weathered outcrop shows the permanent color of the rock after long exposure to the weather.

NECESSITY FOR CORE DRILLING.

Surface observations alone must, however, be deemed insufficient except where very small quarries are contemplated. Information obtained from surface study should be supplemented by records of core drilling whenever possible. The larger quarry companies in northern Ohio spend several thousand dollars every year in keeping core drills constantly in operation. The information gained from the drill cores enables them to plan their quarry work at least five years ahead. Companies who take such precautions are not working blindly; they know not only the amount of stone available over a given area, but also the amount of each particular variety. If the drill cores show that by further extension of the quarry opening the proportion of rock of one particular variety will increase, the quarry operator may take advantage of this advance information and develop his market by seeking orders for that grade.

The information obtained as to quantity of rock is no less important than that relating to quality. It is unsafe to assume that sandstone deposits are of uniform thickness, even for short distances. An instance cited by Bownocker[a] illustrates the possible variations that may be encountered. At West View, Ohio, two wells only 300 feet apart penetrated Berea sandstone. In one well the sand-

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[a] Bownocker, J. A., Building stones of Ohio: State Geol. Survey, ser. 4, Bull. 18, 1915, p. 73.

stone was 150 feet thick, and in the other only 52 feet thick. Such extreme variations are accounted for by the theory, which is well supported by observations at various places, that the sandstone was deposited on an uneven floor, intersected by hollows and crossed by ridges. As the sandstones were deposited the greater accumulations took place in the valleys, and the hills received only a slight covering. After the sandstones were consolidated and elevated above the surface of the ocean, streams began cutting new valleys and reducing in thickness or entirely removing the beds at many points. Thus it may be seen that both the upper and the lower surfaces of the rocks are subject to great irregularity. It is clear, therefore, that the extent of a sandstone deposit is uncertain, especially when only small and scattered outcrops are to be found. Valuable as the information obtained from a study of outcrops may be, knowledge thus obtained should, wherever possible, be supplemented by a study of drill cores.

Core-drill prospecting in sandstone is usually done by means of a rotary drill that uses steel shot as abrasive. A convenient size of drill core is 4 inches in diameter. The cost may not exceed $1 per linear foot in sandstones of the northern Ohio type. Such cores show thickness and quality of the beds, presence or absence of open bedding planes, interbedded foreign materials, cross bedding, etc.

DRILL-CORE RECORDS.

Accurate records should be kept of every drill hole, and a map should be made showing the exact location of each hole. In describing the location of drill holes, a fixed base is desirable. The driller may unthinkingly locate the drill hole by stating that it is situated so many feet in such a compass direction from a certain derrick. In the ordinary process of quarrying, the derrick may be moved to a new setting, and the record then becomes useless, and the drill hole can not be located. A method adopted by one quarry company is to locate all drill holes from a concrete pillar. Every drill hole is mapped and a record kept of the exact thickness of each type of stone encountered.

PROSPECTIVE QUARRY CONDITIONS.

In addition to quality and supply of the rock, other factors demand consideration. The composition and depth of stripping necessary, the best method of removal, and the place of disposal must be studied, in an endeavor to estimate the probable stripping costs per cubic foot of rock produced. Other matters of importance are transportation facilities, cost of sidings, nearness of market, freight rates, and outlet for by-products.

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EXAMPLES OF LOSSES DUE TO INSUFFICIENT PROSPECTING.

As an example of inadequate prospecting that led to disastrous results, reference may be made to a quarry the land and equipment of which represented an investment of $25,000. It was operated for 10 years with ever-increasing difficulties and losses, and then abandoned because a sufficient supply of material of the original grade could not be obtained. No core drilling was done prior to the commencement of operations, as it was assumed that rock of the quality then uncovered was of wide extent.

A quarry now in operation has over 20 feet of stripping and only a 12-foot rock face. The removal of so much stripping for a thin ledge of rock is expensive. It is obvious that if the quarry could be continued to greater depth, stripping costs per cubic foot of stone produced would be greatly reduced. In view of this possible reduction in the cost of production, it is apparent that core-drill investigations would be justified, but up to the present time they have never been made at the quarry mentioned.

STRIPPING.

The term "stripping" is applied to the waste material, or overburden, that overlies the quarry ledge. The term is also applied to the process by which this material is removed.

COMPOSITION AND THICKNESS.

The nature and thickness of waste material that overlies rock deposits is variable, and rarely is a ledge entirely free from it. In the case of bare outcrops, the surface rock is usually partly decayed and disintegrated, and for all practical purposes may be regarded as stripping, as its removal is necessary before good rock is reached. Sand, gravel, clay, shale, and thin-bedded waste sandstone are the common materials overlying serviceable stone. A soil covering may be absent or may attain a thickness of 50 or 60 feet. Where an opening is made on the face of a hill, stripping may at first be light, but commonly increases greatly as the quarry face is extended back into the hill.

An intimate relationship exists between the thickness of stripping and the thickness of available stone. It may happen that only a limited thickness of rock is of quarryable quality, and in such a case the quarry must have a wide lateral development, and stripping, therefore, becomes a matter of great importance.

If, on the other hand, the quarry may be continued to great depth, lateral development will be comparatively slow, and a heavy stripping will present less difficulty.

Although an excessively heavy overburden is to be deplored, a moderate depth of stripping is in some instances more advantageous to the quarryman than is the entire absence of overlying débris. Bare, exposed outcrops are usually altered by weathering to a depth of several feet, but a moderate depth of overburden affords sufficient protection to preserve the rock from decay. If the cost of removal of waste rock in the one case is more than that of the soil removal in the other, a soil protection is to be desired. The quarryman as a result of superficial observation of the surface conformity adjacent to his quarry opening may welcome a depression which materially reduces the depth of stripping, but may find later that otherwise good beds are unsound, or stained, and thus of inferior quality on account of insufficient protection from surface weathering.

EXPENSE OF REMOVAL.

The expense involved in the removal of stripping depends on the amount of material to be moved, the convenience of a place of disposal, and the degree of efficiency attainable in the method and equipment employed. The cost of removal of a heavy stripping may constitute one of the largest items in the cost of quarrying. The author is convinced, however, that in many places this item of expense could be greatly reduced by using improved methods and machinery. Figures obtained from various quarry operators show a remarkable range in the cost of soil removal. The lowest was 3 cents and the highest 31 cents per cubic yard. The low figure was obtained through the use of a large steam shovel at a quarry where the place of disposal was within reach of the shovel, no car transportation being necessary.

METHODS OF REMOVAL.

SHOVEL AND DUMP CART.

Loading into dump carts by hand labor and hauling away by mules or horses is a method that may be justified under certain conditions, as, for example, where the stripping is too light and the distance to which it is to be removed is too great to justify more expensive and what is usually more efficient equipment. However, the method is usually slow and expensive and one for which more economical methods could be easily substituted in many instances.

SHOVEL AND DERRICK BOX.

The derrick box is usually employed to remove débris that has fallen into the quarry excavation. It is commonly used also for the removal of stripping from otherwise inaccessible quarry ledges. In

any case, it is a slow and expensive process, and an effort should be made to avoid it wherever possible. By stripping some distance ahead of subsequent quarry operations, more economical methods may be used.

SHOVEL AND DUMP CARS.

Where it is necessary to remove the stripping to a considerable distance from the quarry opening, the derrick box may be placed on a dump car that runs on a track. If a tramway can be constructed to the quarry face and the soil loaded directly into dump cars, the operation of hoisting by means of a derrick and placing the boxes on the cars may be eliminated. This method is used in a quarry near Medina, N. Y. The tramway in this quarry meets the face of the pit at the level of the rock surface and extends back on a down grade to the excavation from which all the useful rock has been taken. Thus the loaded cars run downhill.

Dump cars are employed in quarries near Pittsburgh, Pa., for the removal of clay stripping to brick plants. At Walkers Mill, Pa., a clay or shale stripping is conveyed in dump cars over a tramway level with the rock surface, which is about 20 feet above the quarry floor, and is dumped into a hopper at the brick plant. The cost of throwing down the clay and subsequently lifting it is thus saved.

CLAMSHELL BUCKET AND TRAVELING CRANE.

In quarries where a traveling railway crane is employed to handle blocks of stone, a clamshell bucket operated by the crane may be used successfully as a substitute for a steam shovel for working into the face of a bluff. It gives fair service, and as the cost of the bucket is nominal the heavy first expense of a steam shovel is saved. This method is employed in quarries near Portland, Conn., and near Amherst, Ohio. The cost of removal per cubic yard is in general much lower by this method than by any of the methods mentioned previously.

STEAM SHOVEL.

For the removal of heavy stripping from wide areas the steam shovel is probably the most efficient device. The cost per cubic yard depends on the depth and nature of the stripping, the distance to which it must be removed, and the size of the shovel. Proper judgment should be exercised in purchasing a steam shovel, in order that it be of a size commensurate with the work required of it. If too small, the necessary work will not be accomplished in the time available. If too large, the interest on investment will unduly increase

the cost of excavation per cubic yard. Every circumstance must, however, be carefully considered. It may be that by purchasing a steam shovel of extra-large size the boom may be of sufficient length to remove the stripping to its final destination without the use of cars. If a small steam shovel were purchased, the first cost, and, therefore, the interest on the investment, would be much less, but to offset this there would be the expense of maintaining cars and tracks and the additional time and labor required for car transportation. Thus it is possible that the purchase of the larger and more expensive machine would be more economical in the end.

Steam shovels are employed for stripping in sandstone quarries near Berea, Sherrodsville, Vincent, and McDermott, Ohio.

OVERHEAD CABLEWAY.

As an illustration of an overhead cableway for stripping, a description of the system in use at a quarry near Peninsula, Ohio, may be of interest. The soil stripping is 7 to 15 feet thick and is stripped back into the old quarry pit. The cable is 2½ inches in diameter and 900 feet long, the distance between the towers being 650 feet. Each tower consists of a pair of timbers converging toward the top and braced with cross timbers between. The cable passes over the towers and is anchored at the ground at some distance back of them at either end. The usual system of buttons and stops is employed to hold up the slack of the cable. Large pans are loaded by hand shovels, removed by the cableway, and dumped. One of the advantages of this method is the shortness of the time required for the removal of the loaded pan, the disposal of the material contained therein, and the return to the place of loading. During one winter 10,000 cubic yards of soil was removed by this method at the quarry cited.

The cableway is much easier to erect than a tramway, is much less in the way, and permits a rapid rate of handling the material. The success of the method would seemingly justify its use in other places.

DRAG-LINE SCRAPER.

A drag-line scraper consists of a pair of buckets or scrapers on an endless cable. Beginning from the drum of the hoist the cable passes around a sheave attached to a post or stump close to the area to be stripped. From this it extends to a second sheave attached to a tree or mast which is situated just beyond the point where the stripping is to be dumped, runs to a third sheave close to the first one, and from this to the drum. As the drum revolves, one bucket scrapes up a load and carries it to the dump while the empty one returns, as shown in Plate I, *A*. When the drum is reversed the previously

empty bucket carries out a load. The loaded scraper drags on the ground until the edge of the hill is reached. The sheave is placed in an elevated position, and as the scraper nears it the latter is raised to a nearly vertical position, permitting the earth to slide out as shown in Plate I, *B*. The field of operation may be shifted laterally by moving the sheaves to various masts or other supports. A row of trees situated sufficiently beyond the brow of a hill to leave space for dumping serves this purpose admirably. The tree shown in the background of Plate I, *B*, has been utilized in this way, as evidenced by the pile of earth beside it.

If the stripping is too hard for the scraper to pick up readily, loosening by blasting may be advisable. Springing the holes with dynamite and then blasting with black powder is a method that has met with success.

The drag-line scraper equipment is simple and inexpensive and has given efficient service. The substitution of a drag-line scraper for dump carts has in one instance reduced the cost of stripping more than 100 per cent. It should be noted, however, that this method can be employed only under certain conditions There must be a convenient place of disposal for the stripping adjacent to the area to be stripped, and preferably at a lower level. Furthermore, the surface conformity must be such that the loaded scraper can be dragged along the ground until the dumping place is reached. The most favorable situation for use of a drag-line scraper is at the top of a bluff which falls away steeply from its edge and over which the stripping may be thrown.

DISPOSAL OF STRIPPING.

Disposal of stripping is greatly facilitated if a valley or depression is near at hand in which it may be dumped. Where quarries are situated on hillsides, it may usually be transferred to an easy dumping ground over the edge of the bluff, as at Farmer, Ky., and Glenmont, Ohio.

A common practice among sandstone quarrymen is to utilize abandoned pits or the worked-out parts of large excavations as dumping grounds. Usually such pits are situated close to the area to be stripped, and the low level affords an easy and cheap method of getting rid of overburden. Quarry pits offer so many advantages for utilization in this way that they are sometimes filled without sufficient forethought. The quarry operator should be perfectly sure that all available stone has been removed from the excavation before filling is begun. An instance has been observed of stripping back into a shallow pit where no effort had been made to investigate the nature of the beds below the existing quarry floor and where it

A. A DRAG-LINE SCRAPER USED FOR STRIPPING IN A SANDSTONE QUARRY NEAR FARMER, KY.

B. THE METHOD BY WHICH THE DRAG-LINE SCRAPER BUCKET IS AUTOMATICALLY DUMPED.

seemed probable that good rock could have been obtained by quarrying at deeper levels. Filling up the pits in this way has effectually prevented continued excavation at deeper levels, and whatever good rock may be present beneath these great piles of débris is no longer available. Core-drill prospecting should first be conducted in such quarries in order to determine the nature and thickness of the beds below the quarry floor and thus enable the quarryman to judge whether filling is justifiable, or if the pits should first be worked to greater depths.

Another mistake in the disposition of soil in quarry pits is the failure to leave adequate space between the working place and the pile of débris. An effort to cut down the expense of transportation may result in dumping so close that the working face may be fouled. Plate II, *A*, represents such an unfortunate condition, where the working face is completely buried by the pile of débris at the left. In order to quarry out the beds, it becomes necessary to channel a new cut, leaving a wall of bedrock to hold back the soil. The waste of rock, together with the additional expense of channeling and removing key blocks, should discourage such an inefficient method of removing stripped material.

Certain sandstone quarries are so situated that disposal of overburden is a problem of exceptional difficulty. Where quarries are situated on steep hillsides, with roads or railroads at the base of the hill, the process of stripping may be expensive as the material must be carried by tramways or cables to points beyond the transportation lines. The fact that the depth of overburden in such quarries usually increases greatly as the excavation is extended into the hill increases this difficulty. It is suggested that the operators of quarries thus situated study carefully the problem of tunneling as presented in a subsequent part of this bulletin. If tunneling can be successfully employed the overburden may be left undisturbed.

UTILIZATION OF STRIPPING.

In some instances the overburden is of such a nature that it may be utilized for the manufacture of by-products, and the net expense for stripping may be greatly reduced, or the overburden may even be removed at a profit. Certain quarries near Pittsburgh utilize a clay or shale overburden for the manufacture of brick and tile, and a sandstone quarry near Cleveland contemplates the establishment of a vitrified-brick plant to utilize shale stripping.

In other localities the products of stripping are utilized to advantage in improving quarry property by filling in depressions around quarries or shops, or in grading roads and railroads. At Berea, Ohio, abandoned excavations are filled to the original level,

and are used for building lots. Areas from which all the serviceable stone has been removed are thus rendered productive and bring an income to the quarry company.

TIME DEVOTED TO STRIPPING.

On account of the injurious effects of frost on freshly quarried sandstone, removal of stone from the ledge is usually abandoned during the late fall and winter months. The winter period, during which quarrying is inadvisable, is usually devoted to stripping a floor of sufficient extent for the subsequent season's operations. Aside from the necessities of the case such alternation of process offers certain advantages. Centralization of effort tends toward increased efficiency. When stripping and quarrying are conducted simultaneously there is likely to be a divided superintendence with possible inefficiency due to lack of supervision. To avoid this condition a larger force of superintendents may be employed, resulting in excessive overhead expense. Where quarrying is conducted in summer and stripping in winter one superintendent can control both operations and devote his whole attention to each in its appointed time.

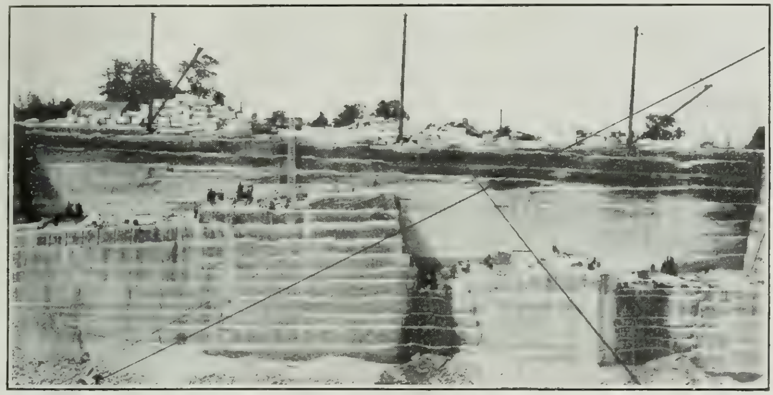
Another advantage of winter stripping is the noninterference of operations. When quarrying and stripping are carried on at the same time, the equipment employed for one purpose may come into conflict with that used for the other.

Where a clamshell bucket and a locomotive crane may be employed for stripping, and the locomotive crane without the bucket is employed for handling rock, the same expensive machine may be used for both operations, when these operations are conducted at different times, whereas a duplication of machinery is necessary for simultaneous stripping and quarrying. It is also quite possible that some of the more efficient stripping equipment, such as overhead cableway hoists or drag-line scrapers, could not be used in many instances if rock quarrying were conducted at the same time as stripping, as the stripping equipment would be too much in the way of rock-quarrying operations. Furthermore, the power plant may be overloaded to the point of doubtful economy.

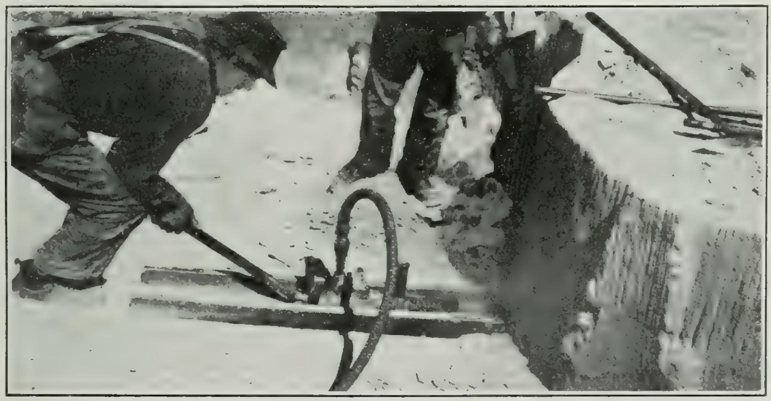
Where blasting is done in quarrying or stripping it is often necessary, when shots are fired, that both gangs suspend work while seeking places of safety, perhaps at great loss of time.

Where the floor is stripped ready for a whole season's work, a clear field is provided for quarry operations. The quarryman can place his derricks more advantageously and plan his work better when a wide area is stripped and when there is no conflict with other operations.

A. QUARRY WORKING FACE FOULED BY STRIPPINGS DEPOSITED IN THE PIT.



B. FACE IN A LARGE SANDSTONE QUARRY NEAR AMHERST, OHIO.



C. A SLIDING DRILL EMPLOYED FOR MAKING HORIZONTAL DRILL HOLES AT QUARRY FLOOR

Moreover stripping is usually more economical when kept well ahead of rock quarrying. There is less danger of débris falling into the pit, from which it is usually removed by inefficient means. Also the removal of stripping from narrow ledges and awkward corners is often accomplished with a derrick box and a hand shovel, whereas removal from a wide ledge could be done with much more rapid and efficient equipment.

CONDITIONS FAVORABLE FOR ECONOMICAL METHODS.

The various features referred to in the preceding section suggest to the sandstone quarryman that a seasonal alternation of processes is eminently favorable for efficient operation. With a full gang, undivided superintendence, and an undisturbed field for activity, the most improved equipment and the most efficient methods may be adopted.

QUARRY OPERATIONS AND EQUIPMENT.

FACTORS GOVERNING EFFICIENCY.

The various operations by means of which sandstone is quarried are channeling, drilling, blasting, wedging, moving, and hoisting. A discussion of these operations involves consideration of types of equipment generally employed and the conditions that govern efficiency in all stages of quarrying. It is well to remind operators also that efficiency in quarrying demands not only efficiency in each of these operations, but also demands that wherever one operation may be substituted for another, the more efficient shall be the one employed. For example, wedging may be substituted for blasting, or vice versa, or either wedging or blasting may be substituted for channeling in certain cases. Some of these operations are more expensive than others per cubic foot of rock produced, whereas the cheaper methods may be more wasteful of rock. It follows, therefore, that the value of the rock has an important bearing on the proper balance to be maintained between various operations that may be substituted the one for the other. If the rock is low-grade, cheap and rapid methods, even though they are relatively wasteful, may be justified. If on the other hand the rock commands a high price, methods that are less wasteful of material, though more expensive in operation, may be substituted.

GENERAL PLAN OF QUARRYING.

Before a detailed discussion of the various steps to be followed in stripping and removing sandstone blocks from the ledge is presented, a brief statement may be given of the chief structural features

that affect the general plan of quarrying, and the most successful methods that may be employed under certain conditions.

INDURATION AS A FACTOR.

As previously pointed out, sandstone is probably the most variable in workability of all the common structural stones, owing mainly to the condition of cementation of the constituent grains. When the grains are firmly cemented the rock is said to be indurated, and an extremely indurated rock with a siliceous cement is termed "quartzite." When the grains are so loosely cemented that the rock may be crumbled in the fingers, it is said to be friable. Sandstones occur having their grains cemented together with all degrees of cohesiveness between these two extremes. Naturally the more indurated types are those presenting the greatest difficulties in working.

QUARRYING OF SOFTER TYPES OF SANDSTONES.

Types of sandstone that show little induration are quarried extensively in the United States. The structural features having the most pronounced effect on general quarry methods are the presence or absence of open bedding planes, the thickness of the beds between open bed seams when the latter are present, and the spacing and the arrangement of joints.

Channeling machines may be employed in all sandstone quarries of this type. The extent to which they may be used depends mainly on the joint systems.

The various types of softer sandstone deposits are discussed in the following paragraphs:

SANDSTONE WITH FEW OPEN JOINTS.

In deposits with few open joints channeling machines are used for wall cuts and to cut out the larger masses of rock, except where a joint may be utilized to take the place of a cut. Subsequent division of these masses is accomplished by means of blasting or wedging. The larger quarries in northern Ohio, one of which is shown in Plate II, *B*, are of this type.

SANDSTONE WITH PARALLEL JOINT SYSTEMS.

In sandstone deposits having joints approximately parallel, spaced 20 to 50 feet apart, and in one system only, back-wall cuts are made with a chaneling machine. If the joints are in two intersecting systems, channeling may not be necessary. Some of the Portland (Conn.) quarries are of this type. In these quarries channeling ma-

chines are used only for back-wall cuts or for the removal of key blocks, open joints taking the place of channel cuts in many places.

SANDSTONE WITH IRREGULAR OR ACUTELY INTERSECTING JOINTS.

In deposits with irregular or acutely intersecting joints quarrying is usually conducted without channeling machines, the larger masses being broken free by blasting. An effort is always made to work into the deposit in the direction of convergence of the joints, in order that the rock masses may not bind against the walls when removal is attempted. Sandstone deposits near Springfield, Mass., and near Hummelstown, Pa., are of this type.

INFLUENCE OF BEDDING ON QUARRY METHOD.

If in any of the above types the sandstone is massive and tight-bedded, floor breaks by wedging are necessary. The deposits near Amherst, Ohio, are of this type. Many sandstone deposits, however, are open-bedded. Those near Berea, Ohio, are mostly heavy-bedded, some of the beds attaining a thickness of 10 or 12 feet and separated by open bedding planes which are remarkably smooth and uniform. In such heavy-bedded deposits large masses are channeled out and subsequent breaks are made by powder shots, the Knox system being employed.

Thin-bedded deposits are of common occurrence. In sandstone deposits near South Euclid, Ohio, McDermott, Ohio, and Farmer, Ky., many of the beds are only a few inches thick, and rarely exceed 3 feet. In such deposits wedging usually gives better results than blasting, as the breaks are straighter, and there is less shattering of the rock adjacent to the plane of separation.

QUARRYING OF INDURATED SANDSTONES.

On account of the hardness of indurated sandstones their quarrying is more expensive than that of the softer types, and the problems connected with their quarrying are correspondingly more complex. As the result of observations in many quarries, the author has come to the conclusion that sandstones that are sufficiently indurated to make paving blocks are in general too hard to be channeled profitably. Blasting or wedging must therefore be substituted for channeling. A discussion of the methods employed in quarrying various types of indurated sandstone deposits follows.

FLAT-LYING, INDURATED SANDSTONE WITH FEW OPEN JOINTS.

Along the bluffs of Kettle River, Minn., there outcrops a heavy-bedded, flat-lying, indurated sandstone with some irregular unsoundness, but few continuous open joints. Heavy beds, 12 to 14 feet

thick, are separated by thin bands of shale. Each of these thick beds is divided into a number of beds, 2 to 4 feet thick, with somewhat irregular and noncontinuous bedding planes. Vertical open joints are spaced 40 to 300 feet apart. At least four methods of quarrying such deposits are possible; these are described in the following paragraphs.

The first method is to work out the thin beds individually by blasting out masses of considerable size and making further separations by wedging. Where this method is followed the waste appears to be excessive. Figure 2 shows a quarry floor where this method of removal is employed. The rows of holes designated *x* were

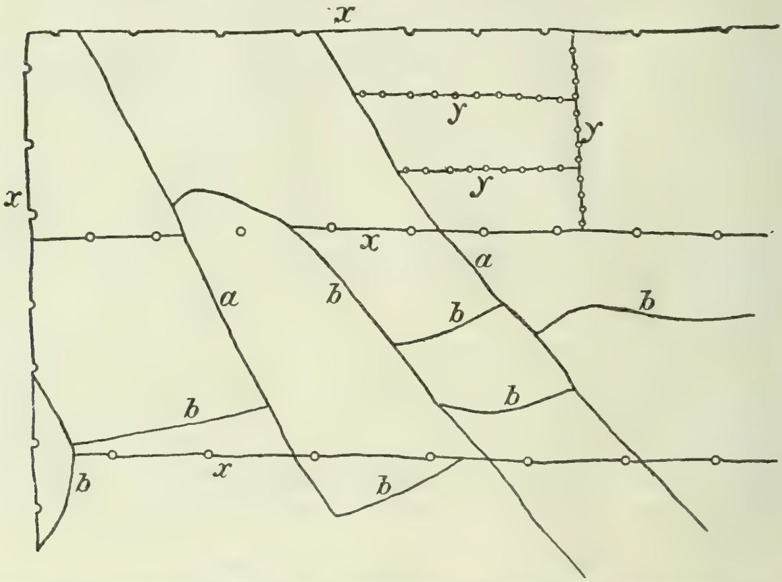


FIGURE 2.—Fractures on quarry floor where excessive blasting has been employed. Fractures *x* made by blasting; *y*, by wedging; *a*, natural seams; *b*, powder shakes.

shot with light powder charges. The holes in rows *y* were wedged. The lines *a* represent natural seams in the rock, and the cracks *b* represent powder shakes, though some of them may follow blind seams. It is evident from the figure that the method employed results in an excessive number of angular or irregular blocks.

The direction of the two open seams *a* suggests that less waste would ensue if the lines of drill holes were made parallel with and at right angles to them. The results obtained indicate that this method is not to be recommended.

A second method is to blast out masses 40 to 80 feet square and the full depth of the heavy beds between the shale beds. Holes 3

inches in diameter at the top, 3 to 4 feet apart, and the full depth of the bed, 12 to 14 feet, are projected in two lines, as shown at *a* and *b*, figure 3. The Knox system of blasting is employed. By simultaneous discharge of black blasting powder in these holes the entire mass is separated from the quarry ledge at one operation. This involves what may be termed a "corner break," by which is meant a simultaneous separation of the rock along two faces meeting at a corner. It is evident that the block is forced to move in a diagonal direction, a process that requires great force to accomplish. On this account the charges must be heavy, and in consequence the shattering of rock adjacent to drill holes is excessive.

A third method, which affords much greater efficiency in blasting, is to separate masses of the same dimensions as those described above by first channeling one wall cut, giving three free vertical faces, and then blasting the remaining face. It is probable that less than one-third of the amount of explosive is required to separate a mass having three free vertical faces than is required to separate the same mass having only two free vertical faces. The success of the method depends, however, on the possible rate of channeling. If the sandstone is highly indurated, the cost of channeling even a single face may be prohibitive.

The fourth method is to separate masses the sizes of which are governed by the spacing of the seams, the latter being utilized to take the place of channel cuts and thus give the free vertical faces without channeling. This method may be used in deposits in which the cost of channeling is excessive. If the seams are 30 to 50 feet apart, no difficulty should be encountered, but if they are 100 to 300 feet apart, some quarrymen doubt the wisdom of blasting such large masses at one time. No examples of such extensive blasting in structural sandstone have been observed, but it seems reasonable to assume that the proportion of waste would be no greater, and probably would be less, in breaking a mass 300 feet long than in breaking one 40 feet long. In a certain Maine quarry the writer observed a mass of granite 300 by 40 by 18 feet that had been successfully broken loose by blasting.

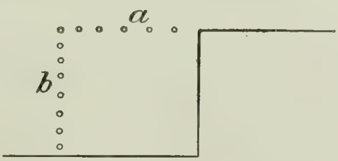


FIGURE 3.—Arrangement of drill holes for a "corner break."

The fourth method appears to be the most promising in highly indurated sandstone.

STEEPLY INCLINED BEDS OF INDURATED SANDSTONE.

Deposits near Potsdam, N. Y., represent another type of indurated sandstone differing from that previously described mainly in the attitude of the beds, which in this locality dip 20° to 25° and have

no interbedded shales. Bedding planes are 3 to 8 feet apart. The beds are worked one at a time, first by blasting according to the Knox system, and subsequently by wedging. Channeling has not been attempted, as the rock is extremely hard.

INDURATED SANDSTONE WITH OPEN PARALLEL JOINTS 20 TO 40 FEET APART.

Another type of indurated sandstone occurs in western New York, in the neighborhood of Medina, Eagle Harbor, and Albion. It is a heavy bedded rock with approximately horizontal open-bed seams, and with one definite system of nearly parallel vertical joints 20 to 40 feet apart. The quarry face is maintained at right angles to the joint system and the joints may therefore be utilized to give a third free vertical face, and thus obviate the necessity for channeling, a process that would be costly in rock of this type. The joints also free the quarryman from the necessity of making "corner breaks," which, as shown above, represent an inefficient type of rock removal by blasting.

EXTREMELY INDURATED SANDSTONE.

The most highly indurated sandstone is termed quartzite. On account of its extreme hardness it is not quarried extensively for structural purposes. A small amount of structural quartzite is produced in southwestern Minnesota, eastern Pennsylvania, and a few other localities. Channeling machines can not be used in quartzite. The larger masses are separated by blasting, and subsequent breaks are made by wedging. Profitable quarrying for structural uses depends largely on the ease of bed splitting and on the presence of conveniently spaced vertical open joints.

DEEP QUARRYING.

The thickness of available stone is an important consideration in working out a general plan of quarrying, especially if a great depth of stripping must be removed. If the deposit is deep a large mass of stone may be removed without stripping an excessively wide area. Thus, near Amherst, Ohio, quarries are projected downward more than 200 feet.

WIDE AND SHALLOW QUARRYING.

In other deposits the available beds may be only a few feet thick. If such deposits are covered with a great depth of soil and waste rock, the cost of stripping may be very high. Thus, in certain quarries near McDermott, Ohio, a shallow deposit is covered with 25 to 30 feet of soil. Successful quarrying of such deposits demands the most efficient equipment for stripping, such as steam shovels and

extensive railway trackage. The quarry equipment must also be of a type that is easily moved.

QUARRYING IN ACCORDANCE WITH JOINT SYSTEMS.

If joints are present in parallel systems, every effort should be made to channel, blast, or wedge parallel with or at right angles to the joints whenever right-angled regular blocks are required. If the cuts make oblique angles with the joints, angular masses will be produced, and excessive waste must result.

In Bureau of Mines Bulletin 106[a] a detailed discussion is given of the economy of quarrying marble in accordance with joint systems. The principles involved are equally applicable to sandstone, and readers interested in this phase are referred to Bulletin 106 for a more complete discussion.

QUARRYING FOR CRUSHING.

In quarrying for the production of crushed stone, rock structures may be disregarded except in so far as they assist or retard breaking and removing the rock. If the beds are inclined, quarrying may proceed down the dip, up the dip, or from the edge of the beds. Working down the dip is usually not advantageous; the floor of the quarry will tend to follow the bedding, and transportation of rock will therefore be always uphill. Moreover, it is more difficult to throw down the rock at the quarry face and therefore more explosive is required when the explosive must move the rock up the incline of the beds. Working up the dip removes both of these difficulties. Working in at the edge of the beds is satisfactory. This method is followed in a quarry at Williamsport, Pa., and also in one near Pittston, Pa.

CHANNELING.

EARLY METHOD OF CHANNELING.

When sandstone was first quarried in the United States, channels were cut with picks in two directions at right angles to each other, and wide enough to admit the body of a workman. This method was wasteful of rock and very slow. Steam-driven machines capable of cutting channels 6 inches wide, or less, were introduced about 1880.

CHANNELING MACHINERY.

Channeling machines of various types are employed in sandstone quarries. They are operated by steam or compressed air. As most

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[a] Bowles, Oliver, The technology of marble quarrying: Bull. 106, Bureau of Mines, 1915, pp. 61–71.

sandstone quarries are of considerable extent, necessitating the employment of machines at a considerable distance from the central power plant, it has been found advisable in many quarries to use steam channelers having attached boilers. When such machines are used, transmission pipes, which are always in the way and difficult to keep in proper condition, are not needed. Electric air machines have been tried, and have worked successfully. For a more complete discussion of channeling machines, the reader is referred to Bureau of Mines Bulletin 106.[a]

RATE OF CUTTING.

The rate of cutting depends on the condition of cementation of the rock, and varies from 100 to 500 square feet per day. The average rate of cutting in any given sandstone deposit is, however, much lower than the maximum rate of which the machine is capable, for, as all quarrymen know, the forcing of a channeling machine to its maximum capacity results in "stunning," a quarryman's term for the production of destructive fractures that run into the sandstone from the walls of the channel cut. If "niggerheads" (indurated or flinty masses) are encountered, the rate of cutting will be temporarily diminished. It may be noted incidentally that such hard masses tend also in many places to divert the channel steel, and thus produce a crooked cut. If the cutting rate of a channeling machine is less than 100 square feet per day, it is probable that its use is not justified.

CHANNELING-MACHINE STEEL.

The steel used for making the channel cut consists usually of three bars clamped together. They are sharpened to a chisel edge, which, however, is blunt and not sharp. Two of the edges are placed perpendicular to the channel walls, and the center one is usually in a diagonal position.

Channeling in sandstone is quite different from channeling in marble or limestone; the rate of cutting may be much faster in sandstone, but the steel wears much more rapidly because of the hardness of the quartz grains. Thus, in the northern Ohio sandstone, in a cut 15 feet long the steel must be changed about every 18 inches on account of the loss in gage from wear by the sand. The first set of bars makes a cut about 4 inches wide, and in order to avoid binding, for each successive cut a set narrower than the one preceding is used. When water is applied the steel abrades much more rapidly. Therefore, to reduce the wear of steel to a minimum, the cutting must be conducted dry or nearly so.

[a] Bowles, Oliver, Op. cit., pp. 53–54.

SAND REMOVAL FROM CHANNEL CUT.

One or two men are employed with each machine to scoop the sand from the cut. In soft sandstones the cuttings from one machine may amount to several tons a day, and the expense of removal is an item of some importance.

Recently experiments have been made in Ohio looking to the adoption of a vacuum cleaner to remove the sand. Although the success of such a method is not yet assured, it is worthy of consideration. As is well known, the sand, if not kept well cleaned out, acts as a buffer, detracts from the efficiency of the blow as the steel descends, and thus reduces the rate of cutting. It is possible that an economical vacuum device could be arranged to remove the sand immediately after it has been cut free, and thus greatly increase the efficiency of channeling as compared with the present practice.

CUTTING OUT CORNERS.

Although some machines are more efficient than others for cutting out corners, there is with any a considerable loss of time. In a quarry near Amherst, Ohio, the cutting out of corners is obviated by making vertical 4-inch drill holes in the corner and terminating the channel cuts in the holes.

FACTORS GOVERNING USE OF CHANNELING MACHINE.

In most sandstone deposits channeling is more expensive than blasting or wedging per square foot of surface obtained, especially in rocks liable to "stunning," when the channeling machine strikes heavy blows. Channeling machines should therefore be used only where substitute methods can not be employed. It is a matter of supreme importance to the quarryman to understand thoroughly the conditions governing the process of block separation, so that he may be enabled to cut down the use of channeling machines to the lowest limit.

The channeling machine is used to make the cuts necessary for the removal of key blocks, and also whatever cuts may be necessary to prepare a block for wedging or blasting. The latter processes are conducted most successfully where the block has five free faces; that is, where only one face remains to be broken free. In figure 4 a block is shown fast to the quarry floor. The four vertical faces and the top are free, and, therefore, it has five free sides, and may easily be wedged or blasted free of the floor. When the floor break *a* is made, further division of the block may be accomplished by wedging or blasting at *b*. For this and each subsequent break there will always be the five free faces.

If joints are not sufficient in number or are not properly spaced to give the requisite number of free faces, the channeling machine is used to make the necessary cuts. The amount of channeling necessary is governed by the size of blocks that can be efficiently separated from the floor if no open bedding planes exist, or, if open bedding planes are present, by the length and depth of a break that can be successfully made by wedging or blasting.

Rock structures have a decided influence on these operations. If open-bed seams are present no bottom break is necessary, and the size of the mass separated is governed only by the ease with which subsequent breaks are made. If straight and uniform breaks of considerable extent can be easily made by blasting or wedging, larger masses may be separated than where uniform breaks are hard to obtain. Moreover, where open bedding planes exist, the bottom, top, and three vertical faces will constitute the five free faces, and the

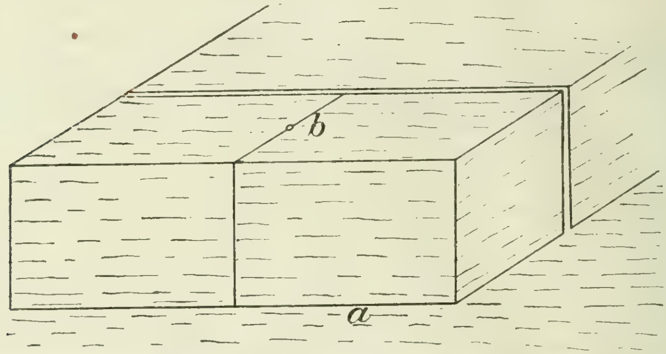

FIGURE 4.—Separation of blocks having five free faces. *a*, first break; *b*, second break.

final break will be vertical. Thus with open-bedded rocks bottom breaks are unnecessary, and one wall cut is saved. Thin beds separated by open bedding planes are rarely channeled except to make one or two wall cuts. It is evident, therefore, that the presence of open bedding planes tends in any case to reduce the amount of channeling necessary, and that if the beds are thin, the amount of channeling is greatly reduced.

If open bedding planes are absent, floor breaks are necessary. If the rock has a rift parallel with the bedding, it may be practicable to lift wide masses, whereas, in the absence of good rift, narrow masses only can be raised. This is well illustrated in the deposits near Amherst, Ohio. In the "split rock"—rock with a good rift—masses 12 to 13 feet wide can be wedged free from the floor, but in the "cross-grain" material—rock with a poor rift—masses only 6 feet wide can be raised. More channeling is therefore required in

rock with a poor rift than in rock in which the rift is more pronounced.

The hardness of the rock also influences the extent to which a channeling machine should be employed. In indurated sandstones channeling may be so slow and the process so destructive to steel that the use of the channeling machine may have to be confined to wall cuts only, or the machine may have to be abandoned entirely and blasting be used. If the rock is so hard that it does not seem advisable to use channeling machines, blasting is sometimes used for a mass with only four free sides. A heavy charge is required and is liable to shatter the rock badly. Selection of the proper method to be employed may be difficult, and in order to reach a decision one must balance carefully the loss due to blasting against the expense of channeling.

The spacing and arrangement of joints has a wide influence on the amount of channeling required. Open vertical joints may in many places be utilized to take the place of channel cuts. Joints are especially advantageous when spaced 20 to 40 feet apart in a parallel system, and if two such systems intersect approximately at right angles, channeling may be unnecessary. If joints are irregular or intersect at oblique angles, blasting may be more economical than channeling.

DIRECTION AND SPACING OF CHANNEL CUTS.

In unsound rock it is always desirable to make the cuts parallel with joints and if practicable to space them in such a manner as to coincide with joints. The economy of channeling in accordance with unsoundness is discussed in detail in Bureau of Mines Bulletin 106,[a] to which the reader is referred.

Where joints do not affect channeling, the arrangement of the cuts is governed by the desired dimensions of the finished product. The arrangement of channel cuts and drill holes in a quarry near Berea, Ohio, is shown in figure 7 (p. 51). After the necessary key blocks are removed masses 26 by 44 feet are channeled out. The presence of open bedding planes permits all subsequent subdivisions to be made by blasting. Successive separations finally give blocks $6\frac{1}{2}$ by $5\frac{1}{2}$ feet, the most convenient size for both curbing and flagging.

CHANNELING CROSS-GRAINED OR INCLINED BEDS.

If, on account of cross grain or a dip of the beds, the rift is inclined to the horizontal, channel cuts should parallel the direction of dip of the rift. If cuts are inclined at an acute angle to the dip

[a] Bowles, Oliver, Op. cit., pp. 61–71.

of the rift the bottom break will run up or down on the rift and produce blocks having undesirable oblique angles, as shown in figure 5. In the figure the quarry floor is shown to be horizontal, merely to emphasize the obliquity of the splitting; in actual practice the floor should parallel the rift.

CHANNELING ON AN INCLINED FLOOR.

In some sandstone deposits the beds are inclined at an angle to the horizontal, and the rift of the rock, or other considerations, make it advisable to incline the quarry floor to parallel the beds. It is customary in such quarries to elevate one end of the track in order that the machine may operate on a level. This is an inefficient

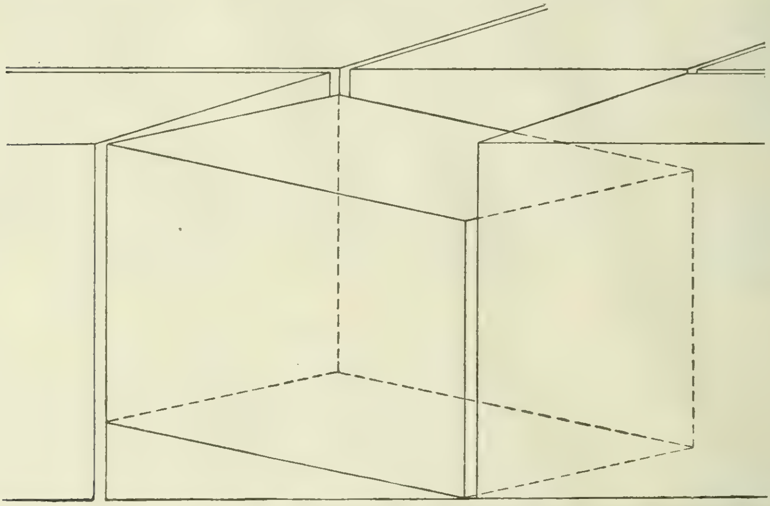

FIGURE 5.—Oblique-angled block obtained when channel cuts are not parallel with direction of dip.

method involving great loss of time in building supports. Furthermore, it necessitates short cuts and frequent changes of steel, and may elevate the machine above the rock surface in such a manner that starting or maintenance of straight cuts is difficult. In certain marble quarries having inclined floors, a track is laid flat on the rock surface in the direction of the dip and a channeling machine is operated on the inclined track. A balance car running on a parallel track is attached to it by means of a cable running over a sheave at the upper end of the channeling-machine track, thus counteracting the effect of gravity, and permitting the machine to operate with equal ease up or down hill. This method has not been employed in any sandstone quarry visited by the author, though a number of quarries were observed where the method might be used to advantage. It is suggested that the operators of sandstone quarries in

which the beds are inclined visit Vermont or Alabama marble quarries where balance cars are employed, and observe the conditions under which such cars may be successfully operated.

DRILLING.

DRILLING MACHINERY.

In the early days of quarrying sandstone near Portland, Conn., a rotating core drill was employed to cut out cores 8 inches in diameter. A can of powder was placed in this hole, with its long axis parallel with the direction in which the rock was to be split. About the year 1880 more modern drills were substituted.

The two chief types of modern drills for quarry work are the tripod or bar drill and the jackhammer. The former is a reciprocating drill mounted on a tripod or attached to a bar that is supported by four legs. When the tripod is employed it must be moved to a new position for each hole drilled. When a bar is used, however, a line of holes may be drilled, the drill being moved along the bar and clamped successively in new positions. Bar or tripod drills are usually operated by steam.

The jackhammer is a name given to a nonreciprocating drill operated without a tripod and provided with an automatic rotating device. It employs hollow steel drill bits, through which the exhaust passes and blows the cuttings from the hole. It gives the best service when operated by compressed air.

It has been found in most cases that compressed air affords certain advantages over steam for the operation of quarry machinery. Where steam is used in quarries there is usually a great deal of loss by condensation, and the variable temperature in the steam pipes makes it difficult to prevent leakage. As a result of these losses, the effective pressure at the machine may be very much lower than the normal boiler pressure. When air is used, the loss in pressure under similar circumstances is not nearly as great. Moreover, when drills are operated by steam, water must be supplied to the drill hole in order to remove the cuttings. This arrangement requires extra labor and keeps the quarry floor wet or muddy. On the other hand, drills of the jackhammer type may be run dry.

If steam is used for drills and the quarry is of wide extent, it is better to have a number of boilers close to points where drilling operations are conducted than to have a central boiler house and to conduct the steam a long distance through pipe lines. Where electric power is available, a portable compressor is sometimes used. It is placed close to the drill, to which compressed air is supplied through wire-wound hose.

The time required to move drills from one position to another in drilling rows of holes is an important consideration, especially in thin-bedded quarries, where the holes are shallow and frequent moves are necessary. In this respect the jackhammer offers certain advantages, as it is held with the hands and no adjustment of supports is necessary. In general, a better time efficiency is obtained where jackhammers are used than where tripod drills are employed.

DRILL STEEL.

The nature of the drill steel is an important consideration in sandstone quarrying, as the sand acts as an abrasive and the drill rapidly loses its gage. Narrow wings wear off rapidly, and consequently the drill steel should be shaped with a view of keeping as much steel as possible near the circumference. Another important consideration is provision for adequate clearance. Most sandstone is cut rapidly, and in order that drills may give efficient service grooves of sufficient size should be provided to permit the cuttings to be removed without difficulty.

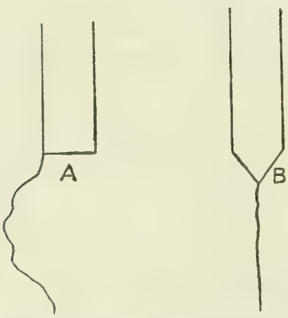

FIG. 6.—Breaks produced by two kinds of drill holes. *A*, irregular break from a square-bottomed drill hole; *B*, straight break from a pointed drill hole.

Drill bushings are commonly hexagonal. It has been found by some quarrymen that square bushings are preferable, as the flat angles of a hexagonal shank wear off quickly. One company found by experience that where a hexagonal shank would last one month a square shank would last a year.

In finishing a drill hole one quarryman recommends the use of a pointed drill, in order to bring the hole to a point. This tends to promote straight splitting, for with a flat-bottomed hole the break may run off to one side, whereas with a pointed hole it inclines rather to run straight from the point, as is illustrated in figure 6.

RATE OF DRILLING.

The rate of drilling is probably more variable in sandstone than in any other kind of rock, on account of the variable hardness. A rate recorded in northern Ohio sandstone is 38 seconds per foot for a $1\frac{3}{4}$-inch hole. In the quartzite near White Haven, Pa., holes of $\frac{1}{2}$-inch diameter are drilled 3 inches deep in about 35 seconds. Thus, for holes of the same size this particular grade of Ohio sandstone is drilled about 45 times as fast as the quartzite.

THE "DITCHER" OR CIRCLE-CUTTING DRILL.

In northern Ohio blocks for making grindstones are quarried in cubical form and the corners scabbled off and wasted. In certain southeastern Ohio quarries a more efficient method is employed for cutting out the circular stones. An air-driven drill of special type is employed to cut a circular trench in the quarry and thus produce blocks of the desired diameter at a single operation.

The "ditcher" is supported by tripod legs and by a vertical bar which fits into a square hole 4 by 4 inches in the rock surface. This hole is made quickly by drilling three parallel rows of three holes each with a small hammer drill, and by cutting out the intervening masses with a pick. The drilling machinery is attached to one end of a heavy crossbar, and a counterbalance weight is attached to the other end. It is rotated by a worm gear. The diameter of the circle to be cut may be varied by bolting the drill attachments in different holes on the bar. In cutting a 7-foot circle the steel is changed for about every 6 inches of depth, each successive drill being about $\frac{1}{4}$ inch smaller on account of the loss of gage by wear. A four-pointed, star-shaped drill head is employed. A sharp-pointed bar is used to trim and straighten cuts where they meet other cuts. It is claimed that a "ditcher" will cut as many square feet per day as a channeling machine. It also takes much less time to set up, as no tracks are required.

By the method used in northern Ohio square blocks are quarried and then subsequently scabbled to a round shape, whereas by the "ditcher" method one operation is saved, as they are cut in circular form in the quarry. There is also a considerable saving of material by the "ditcher" method. When square blocks are scabbled the corners are entirely wasted, whereas by using the circle-cutting device small grindstones may be cut out of the corner pieces, and the waste thereby be greatly reduced.

The drill hole for making the floor break is made by means of an air drill which slides on a horizontal bed as illustrated in Plate II, *C*. The drill is kept in position by the operator by means of a hinged handle and crossbar.

BLASTING.

EXPLOSIVES USED.

The choice of explosives in sandstone quarries depends on the physical properties of the stone, the quarry conditions, and the nature of the product desired. For building stone, grindstones, or other products for which large and sound masses of stone are desired, black blasting powder is used. The force of a dynamite

explosion is too sudden and violent, and may cause much waste by fracturing. In some quarries, however, light dynamite shots are employed, though usually dynamite of as low a grade as 27 per cent is used.

However, where the quarried sandstone is to be used in crushed form, charges of a higher-grade dynamite are employed, as the quarryman then tries to break the stone as much as possible. In one quarry where the rock was to be used in crushed form, it was thrown down in large masses at the face, the dip of the quarry floor necessitating a forcing of the rock up hill, and it was found that a charge consisting of both blasting powder and dynamite gave the best results, as the slower explosion of the blasting powder tended to move the whole mass more effectively.

THE KNOX SYSTEM.

In quarrying stone for building or for other purposes for which sound and regular blocks are desired, the Knox system is almost invariably used. The blast holes are drilled nearly to the bottom of the bed and are reamed or grooved with a flanged tool which is driven into the drill holes by sledging. The grooves, about $\frac{1}{4}$ inch in depth and on opposite sides of the drill hole, should always be made exactly in line with the direction along which it is desired to break the rock. Only small charges of powder are required, as the force of the explosion is rendered very effective partly by reason of the grooves described above, and partly because a considerable air space is left between the stemming and the charge. A plug of cotton or other suitable material is placed in the drill hole some distance above the charge, and that part of the hole above the plug is filled with sand. When an air space is provided in this manner the force of the explosion is exerted over a much wider surface than when there is no air space, and consequently the intensity of the explosion is not localized in one spot, and less fracturing of the rock is likely than in cases where the Knox system is not employed. Moreover, the force of the explosion enters the grooves formed by the reamer, and tends to give a straight break.

In quarries near Berea, Ohio, an important modification of the Knox system has been introduced. For a break 6 feet 6 inches wide on a bed 8 feet thick, a single hole is drilled at the middle, nearly to the bottom of the bed. After the drill hole is reamed a plug of cotton waste is put 2 or 3 feet from the bottom of the hole, and about two handfuls of black blasting powder is added. Another plug is placed about 1 foot from the top of the hole, and the space above it is tamped with sand. Thus an air space is provided both above and below the charge. The shot is fired with an electric firing machine, and remarkably straight breaks are produced.

METHOD OF FIRING SHOTS.

Single shots are commonly fired with a fuse, though there is usually a smaller loss of time when electric firing machines are employed. For the simultaneous discharge of a number of shots electric firing is necessary, and may be accomplished by means of a hand-operated firing machine, or by connection with the quarry current. For details of safe and efficient methods of charging, tamping, and firing, the reader is referred to Bureau of Mines Bulletin 80[a] and Technical Paper 111.[b]

DIRECTION OF DRILL HOLES.

When the beds are flat, or nearly so, the drill holes are made vertical. If the beds are steeply inclined, the drill holes should be inclined to make right angles with the beds, in order that right-angled blocks may be produced.

ADVANTAGE OF SPLITTING PARALLEL WITH RIFT.

In most sandstones the direction of easiest splitting is parallel with the bedding. Usually there is a second direction of easy splitting subordinate to the rift or grain, but commonly rather pronounced. To avoid confusion this second direction of easy splitting is designated the "run of the rock." It usually follows a plane perpendicular to the bedding, and thus in flat-lying beds is in a vertical plane. It commonly follows the same compass direction over an area of considerable extent.

If in the process of quarrying an attempt is made to break the rock in a direction at an oblique angle with the run, two disadvantages are encountered. In the first place, the rock splits with greater difficulty in directions making oblique angles with the run than in directions parallel with the run, and as a consequence drill holes must be more closely spaced and more explosive is required. In the second place, the tendency of the break to follow the run causes a plucking of the rock into V-shaped notches between drill holes, giving an uneven surface and causing waste. As illustrated in Plate III, *A*, if an attempt is made to force a break in a direction oblique to the run, from each drill hole a fracture follows the run for a short distance and then comes out in a curving direction to the next drill hole. Contrasted with this is the smooth surface shown in Plate III, *B*, where splitting is parallel with the run.

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[a] Munroe, C. E., and Hall, Clarence, Primer on explosives for metal miners and quarrymen: Bull. 80, Bureau of Mines, 1915, pp. 17–53.

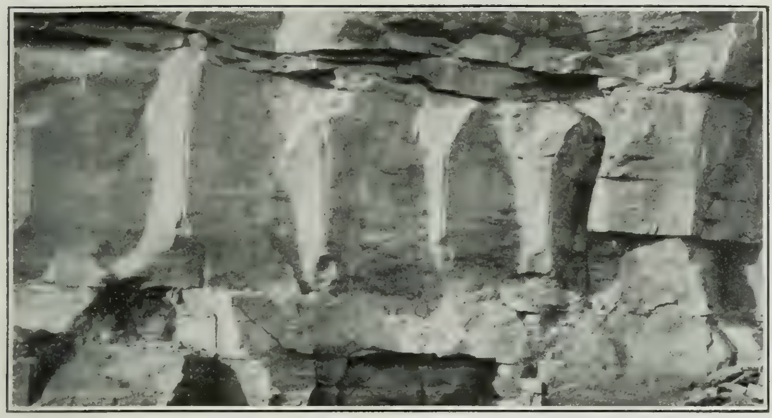
[b] Bowles, Oliver, Safety in stone quarrying: Technical Paper 111, Bureau of Mines, 1915, pp. 18–25.

BLASTING AS SUBSTITUTE FOR CHANNELING.

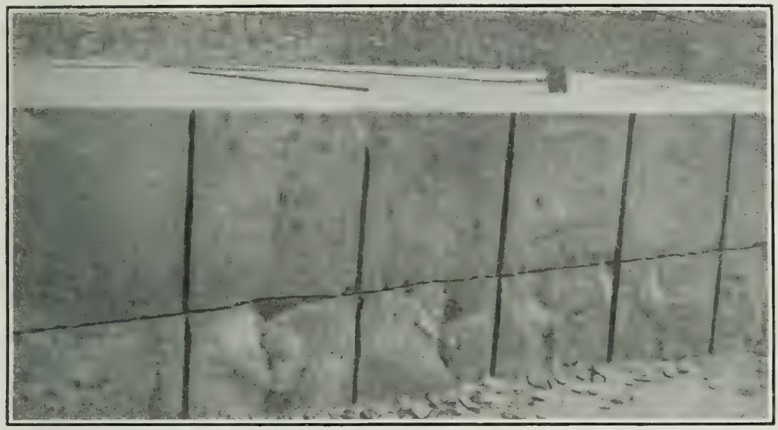
Although in many quarries blasting is used chiefly to further subdivide blocks previously separated from the quarry ledge by channel cuts, under certain conditions it may be advisable to substitute blasting for channeling. Such substitution may be occasioned by irregular jointing or by the fact that the rock is too hard to be channeled profitably.

If irregular jointing is the cause, the aim of the quarry operator is to work out masses of rock between converging joints in order to avoid binding of the loosened mass on the quarry walls when removal is attempted. Drill holes 3 to 6 feet apart, depending on the ease of breaking, are projected nearly to the bottom of the bed, and the Knox system of blasting is employed, the shots being discharged simultaneously by an electric current. There is a difference of opinion among quarrymen as to the amount of explosive that should be employed for such shots. In some quarries charges of sufficient strength are used to move the rock mass bodily a foot or more clear of the wall. In other quarries the charge is of sufficient size merely to cause a fracture without moving the rock appreciably. While there is an advantage in having a space of several inches at the back wall, the waste caused by shattering with a heavy charge is probably too great to justify this method. It is suggested that quarrymen who now employ this method reduce powder charges to such a point that mere fractures are formed and note carefully whether the reduction in waste by shattering is not sufficient to justify the use of the smaller charges.

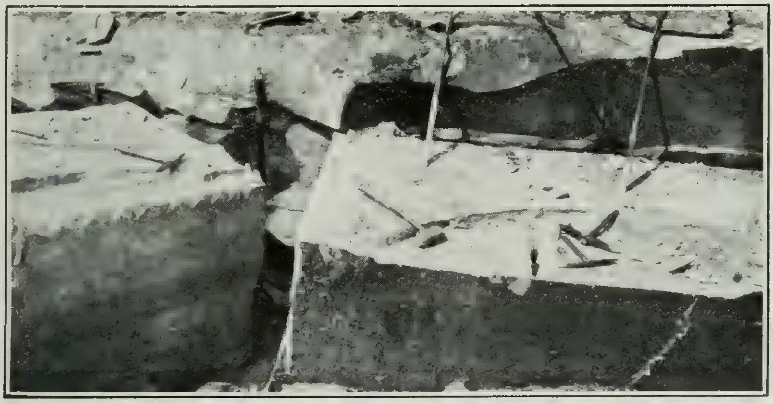
In quarries in which the hardness of the rock makes it advisable to substitute blasting for channeling, success in blasting depends greatly on the arrangement and spacing of open joints. In the discussion of the general plan of quarrying (p. 37), it was intimated that blasting is more effective where there are three free vertical faces than where there are two. Where there are only two free vertical faces "corner breaks" are made, and heavy charges must be used to force the rock mass in a direction diagonal to both lines of drill holes. Moreover, it is evident that heavier charges will be required in the holes in the corner than in those near the margin, and consequently it is a matter of some difficulty to properly balance the charge. With the most favorable adjustment of the charges, much shattering is likely to take place, with consequent waste of both rock and explosive. If joints are spaced far apart it may be advisable to make a third free face by channeling, or to extend the back line of drill holes the full distance between joints, and to move a large mass of rock at a single operation.



A. UNEVEN SURFACE FROM ATTEMPT TO BREAK THE ROCK OBLIQUELY TO THE RUN.



B. SMOOTH SURFACE FROM A BREAK PARALLEL TO THE RUN OF THE ROCK.



C. A CROSS BREAK MADE BY DRIVING POINTS INTO PICK HOLES.

BLASTING FOR SUBSEQUENT DIVISION OF BLOCKS.

CONDITIONS UNDER WHICH BLASTING MAY BE EMPLOYED.

It is customary in most sandstone quarries to channel out large masses of convenient size and shape, free them from the quarry floor if open beds are absent, and subdivide them by blasting or wedging. Blast holes are usually more widely spaced and deeper than wedge holes. Blasting is commonly employed in heavy bedded rock and wedging in deposits that are thin bedded. Where beds are 3 feet or less in thickness it is commonly found that blasting shatters, and therefore wastes considerable rock, and that the surface obtained is usually more uneven than where wedging is employed. In some deposits wedging may be substituted for blasting, even in thick beds.

ARRANGEMENT OF DRILL HOLES.

The preliminary process of rock removal involves the separation of large masses from the quarry ledge, whereas the step now under consideration deals entirely with further subdivision of these masses. A suitable arrangement of drill holes is illustrated in figure 7, which represents actual conditions in an Ohio quarry. The holes are drilled almost to the bottom of the mass and are reamed in the direction in which breaking is desired. The bed is 8 to 9 feet thick, and the drill holes are about 4 feet apart.

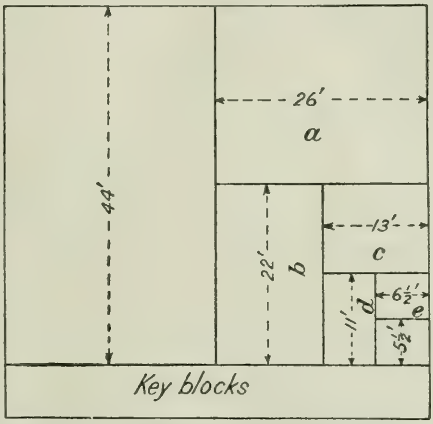


FIGURE 7.—Method of block subdivision in an Ohio quarry. Breaks are made in the order of lettering, *a*, *b*, *c*, *d*, *e*.

ORDER IN WHICH BLASTS ARE DISCHARGED.

The shots are discharged in the order of lettering, *a*, *b*, *c*, *d*, and *e*. The order is governed by the general principle that the straightest breaks are obtained in blasting if the shots are centered, that is, if there is an equal mass of rock on each side of the line of fracture. If the drill holes are so placed that the rock mass is not properly balanced there is a tendency for the break to run toward the lighter mass.

SIZE OF BLOCKS OBTAINED.

It may be noted that this process of block bisection results finally in the production of a series of uniform blocks, each 6 feet 6 inches

by 5 feet 6 inches. This size is the most convenient for both curbing and flagging. Clearly, therefore, proper foresight must be exercised in selecting for the larger masses dimensions suitable for economical subdivision.

RULES GOVERNING MINIMUM NUMBER OF DRILL HOLES.

Figure 8 illustrates the method of block subdivision in a central Ohio quarry. The larger channeled masses are 9 feet thick, 10 feet wide, and about 50 feet long. The shots are fired in the order of lettering, *a*, *b*, and *c*. Attention is directed to the fact that the area or surface obtained in break *a* is 90 square feet, and is made with a charge in a single drill hole placed centrally. When the hole is reamed, care is taken to ream it exactly in line with the direction of the desired break. In this operation the direction of the run, and also the ease with which the rock splits in this direction as compared with other directions, have a decided influence on the number of drill holes and the size of the charge. Obviously, if the original mass is channeled in a direction oblique to the run, there will be a tendency for the break to follow an oblique direction across the block, with consequent waste. If the break is inclined to the run, or if the run is poor, more than one blast hole may be required. It is claimed by most quarrymen that for breaks up to 15 or 20 feet long in heavy beds a powder shot in one centrally placed hole is more effective than shots in two holes in producing a straight break. It is evident that the ease or the difficulty of breaking the rock will be a factor. Furthermore, the single-hole method will probably not meet with success where the mass to be separated is more than twice as long as it is wide. In the latter case it is advisable to use at least two holes, which should be spaced in such a manner that the center space is a little more than twice as long as the end spaces. If the mass to be broken off is a small part of a much larger mass, there is a tendency for the break to slant toward the lighter mass, as shown in figure 9. This tendency may be overcome in part by increasing the length of the middle space, as shown by the dotted lines in the figure.

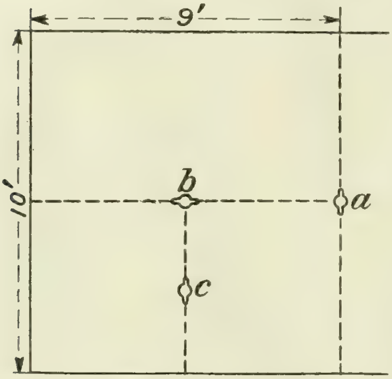


FIGURE 8.—Method of block subdivision in a central Ohio quarry. Breaks are made in the order of lettering, *a*, *b*, *c*.

WEDGING USED IN CONJUNCTION WITH BLASTING.

Occasionally it is desired to break by means of a powder charge a bed that is so thin that effective blasting can not be conducted. The force of the explosion may be supplemented by plugs and feathers. The center hole is reamed and charged, and two smaller holes are drilled in positions as shown in figure 10. The plugs are driven until a considerable strain is placed on the rock before the shot is fired.

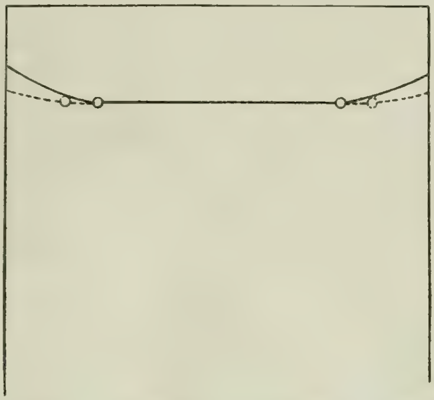


FIGURE 9.—Position of drill holes for breaking off a block more than twice as long as it is wide.

BLASTING TO MAKE FLOOR BREAKS.

Blasting is rarely employed to make floor breaks; wedging is the common method. In one quarry only has the author observed the use of powder to free sandstone blocks from the quarry floor.

BLASTING IN QUARRIES PRODUCING STONE FOR CRUSHING.

Where rock is quarried for use in the crushed form, blasting is done in an entirely different way from that where building stone or grindstones are produced. In a quarry producing building stone or grindstones every precaution is taken to make blasting effectual, and at the same time to preserve the blocks from all unnecessary shattering. In quarries producing crushed stone, on the other hand, the purpose is to break the rock as much as possible. Hence dynamite is used almost invariably, and heavy charges may be employed. Blasting is more effectual, as a rule, when a number of shots are fired simultaneously than when single shots are fired. In quarries with level floors the size of the charge is adjusted to shatter effectively a large mass of rock and throw it down at the quarry

FIGURE 10.—Position of holes for wedging in conjunction with blasting for thin blocks.

face. Where the quarry face is being advanced down the dip of inclined beds the rock may not be thrown down as effectually by ordinary means. One quarryman reports that a mixture of powder and dynamite will give better results than pure dynamite in a quarry of this type.

In unsound deposits an effort should be made to place the drill holes in such a manner with respect to the joints or cracks that the force of the explosion will not be dissipated in the openings within the rock. In some unsound quarries the cost of explosives per ton of rock produced is high on account of the losses that ensue from the gases escaping in cracks.

WEDGING.

THE USE OF WEDGES IN GENERAL.

In sandstone quarries bed lifting is done almost exclusively by wedging. In some thin-bedded deposits the larger masses are separated from the solid ledge by wedging. In thick-bedded rock the subdivision of large masses is usually accomplished by blasting, whereas in thin-bedded stone wedges are more commonly used for this purpose. Small wedges are employed for the division of the smaller pieces into blocks suitable for use as rubble or paving stones.

WEDGING FOR THE FIRST BREAK.

It has been stated that channeling machines are commonly employed to separate the larger masses from the quarry ledge; also that blasting is employed in quarries where irregular jointing or hardness of the rock makes channeling impracticable. However, there are quarries where it has been demonstrated that wedging has advantages over both these methods. In order that wedging may be substituted successfully for channeling and blasting, beds must not exceed 3 or 4 feet in thickness and must be separated by open bedding planes. Such deposits occur commonly, as at South Euclid and McDermott, Ohio, and at Farmer and Freestone, Ky. In such quarries channeling machines are used simply to get free ends from which to work. The wedging method is cheaper than channeling and usually gives a straighter break than blasting.

One method is to make a line of holes about 18 inches apart. The row may possibly be 80 or 100 feet long and 20 to 40 feet back from the quarry face. In one quarry of this type beds 4 feet 6 inches thick are wedged out by this method. Every third hole is made 4 feet deep and the others 2 feet deep. The deep holes are made with a larger drill than the small ones, in order that they may accommodate larger wedges. Two men drive with sledges. The wedges are driven in succession beginning at one end of the line, one blow being given

to each of the smaller and two blows to each of the larger ones. Sledging is continued back and forth along the line of wedges until a fracture appears.

In one Kentucky quarry a mass 100 to 150 feet long and 30 to 40 feet wide is broken from a 3-foot ledge by wedging in drill holes 7 inches deep and 12 to 18 inches apart. In drilling holes only 6 or 7 inches in depth the drill loses little of its gage, and the holes are practically the same size at the top and at the bottom. In wedging there is a tendency, therefore, for the pressure of the wedge to act first at points near the upper surface of the rock, a condition that not only tends to split off thin flakes, but causes loss of efficiency in making the break. This difficulty is overcome in some bluestone quarries by using a "starter" and a "follower"; that is, by drilling the upper part of the hole with a drill of a little larger gage than that employed for the lower part. When this is done the wedges exert pressure nearer the bottoms of the drill holes.

When shallow-hole wedging is employed as described above, it is desirable to make the line of drill holes some distance back from the face. If a wide mass is wedged off, the break will be nearly vertical, whereas if a narrow mass is wedged off, there is a tendency for the break to run toward the light side, as is illustrated in figure 11, and also in the lower part of Plate III, *C* (p. 50).

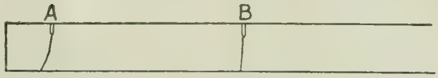


FIGURE 11.—The desirability of making breaks at some distance from face. *A*, Fracture slanting outward from drill holes close to face; *B*, a more vertical fracture resulting from drill holes at a considerable distance from face.

BED LIFTING.

In tight-bedded quarries, when, by means of channel cuts or open joints, four free vertical faces are provided for a large mass of rock, the next step is to free this mass from the quarry floor. This process of separation is known as bed lifting, and the breaks are known as floor breaks. Bed lifting is almost invariably accomplished by means of wedges. If open bedding planes are present this process is of course unnecessary, though subsequent subdivision of the mass may require splitting of a thick bed, a process known among quarrymen of certain districts as "capping." At most tight-bedded sandstone quarries in the United States the rock lies horizontal or nearly so, and in consequence the floor breaks that parallel the bedding are approximately horizontal. Usually the easy splitting way, or rift, in standstone is parallel with the bedding. Although the facility with which floor breaks may be made is variable in different deposits, it is usually accomplished so easily that drill holes are unnecessary. A

notch is cut into the face of the rock to a depth of several inches by means of hand picks. This notch is known among quarrymen as a "grip" or a "side shear." Its lower face is horizontal or with a slight upward slant, and the upper face slants sharply downward, the two faces meeting to form a V. A sharp steel pick is used to finish the grip in order to bring it to a sharp point; otherwise the end of the wedge would strike against the solid rock and would therefore fail to exert the desired effective upward and downward pressure. Blunt wedges are placed in the grip and driven with sledges. In hard splitting rock it may be necessary to place them almost touching each other. Numerous wedges may also be necessary in making an excessively wide break in easy splitting rock. For narrow breaks in easy splitting rock they may be spaced some distance apart. In northern Ohio masses of split rock 13 by 26 feet are lifted by wedging in a grip on one of the long sides. In cross-grained rock, however, the rift is poor, and masses only 6 feet wide are raised.

Occasionally grips are cut on two faces, and the mass is raised by simultaneous wedging at the side and the end. By this means a much larger mass can be raised than when wedging is done from one side only. If the rift is poor, wide floor breaks are not desirable. There is a tendency for the fracture to run up or down or to give an irregular surface, with consequent waste of rock and additional labor in reducing the blocks to proper shape.

In the grindstone quarries of southeastern Ohio, where the stones are channeled out by circle-cutting drills, the masses are occasionally broken from the floor by small powder shots. Usually, however, they are wedged up. To raise a block 7 feet across, a hole is drilled 4 to 5 feet deep, passing under the center of the stone. A long wedge with feathers attached to its extremity is inserted into the drill hole. By driving on this wedge the force tending to lift the stone is exerted at the bottom of the hole. At the floor level a grip is cut around the available circumference of the stone, possibly nearly halfway around, and blunt wedges are driven into the grip. The combined force of the short wedges and the long wedge is sufficient easily to raise the block.

SUBSEQUENT CROSS BREAKS TO REDUCE LARGE MASSES.

CONDITIONS GOVERNING USE OF WEDGES.

Wedging is employed in making cross breaks if it is found that blasting shatters the rock unduly, or if the rock is of such a nature that a straight and uniform break is difficult to obtain by blasting methods. The method of wedging is controlled by the ease of breaking and by the thickness of the beds.

METHOD OF MAKING SMALL BREAKS IN ROCK WITH A GOOD RUN.

In one central Ohio quarry a cross break on a mass 3 feet thick and 4 feet wide is made by driving small points in rows of holes cut with a hand pick (Pl. III, *C*). Small breaks even in tough rock may be made by cutting a continuous grip and driving wedges close together. Breaking may be assisted by marking the ends with a hammer. Usually, however, a cross break requires wedging in drill holes. In thin-bedded rock wedging in shallow holes may be satisfactory.

METHOD IN TOUGH OR HEAVY BEDDED ROCK.

If the beds are heavy or if the rock shows a tendency to break with a slanting or uneven surface, it may be necessary to drill deep holes. Effective deep-hole wedging has received too little attention from sandstone quarrymen. The principles involved may be best illustrated by describing in detail the method pursued in a Connecticut quarry.

METHOD OF DEEP-HOLE WEDGING IN A CONNECTICUT QUARRY.

In order to make a break 12 feet long and 5 feet deep holes are drilled about 4 feet or 4 feet 6 inches deep and $1\frac{3}{4}$ inches in diameter, except at the top, which is $1\frac{7}{8}$ inches in diameter. The holes are 2 feet 4 inches apart. Care is taken to drill them all exactly in the same plane, which in this case is vertical. A channel about 2 inches deep is cut with a hand pick across the rock surface in line with the drill holes. It assists in producing a straight break.

REAMING OF WEDGE HOLES.

Reaming of wedge holes is a noteworthy feature of wedging in this quarry. Although reaming is common in blast holes it is not generally employed in wedging. Reference may be made to an account of an experiment[a] tried in an Alabama marble quarry to ascertain the effectiveness of reaming holes for wedging in marble. It was found that reaming promoted straight splitting with a much wider spacing of drill holes than when reaming was not employed, but difficulty was encountered in making reamers that would not break. Sandstone, however, reams more easily than marble, and nearly every blacksmith employed in connection with sandstone quarries is experienced in making reamers, as they are used almost universally in connection with blasting. It is probable, therefore, that the use of a reamer would increase the efficiency of wedging in many sandstone quarries.

[a] Bowles, Oliver, The technology of marble quarrying: Bull. 106, Bureau of Mines, 1915, pp. 76–77.

EFFECTIVE WEDGES FOR DEEP HOLES.

In the Connecticut quarry under consideration plugs and feathers are made with a uniform taper. They are so constructed that when the plug or wedge is driven the feathers are forced apart a uniform distance at all points from top to bottom. Thus the pressure is uniformly distributed throughout the full length of the wedge. Pressure thus exerted is much more effective than when exerted at a single point or over a small part only of drill-hole wall. Moreover, it is evident that the nearer the wedge faces approach parallelism, the greater is the force that they are capable of exerting. The angle of convergence in these plugs is small and in consequence a fracture is made without heavy driving. Thus much energy is conserved and the lighter driving increases the life of the wedges. For a more complete description of wedges of this type see Bureau of Mines Bulletin 106.[a]

PROCESS OF PLACING WEDGES AND DRIVING THEM.

When holes are prepared for wedging, feathers and plugs are inserted in proper position. A plug of hay or grass fitting snugly in the drill hole is forced down with the feathers, preventing them from slipping down beyond reach. A plug is then placed between each pair of feathers, care being taken to insert it in such a manner that the pressure will be exerted exactly perpendicular to the line of drill holes. If the holes are too large at the top, thin steel shims may be placed between the feathers and the drill-hole walls. The wedges are driven until a fracture appears, four men striking simultaneous blows. In order to avoid unnecessary sledging of the wedges, as soon as a fracture appears, chips are broken out midway between the drill holes and blunt wedges inserted. By sledging on these blunt wedges the pressure is relieved from the long plugs and feathers and they are removed. Heavy steel bars or levers are then inserted a few inches into the drill holes and the block is forced outward.

REMOVING WATER FROM DRILL HOLES.

A simple device for removing water from drill holes consists of a piece of gas pipe 5 to 7 feet long, with a nut or other piece of metal having a round hole, fastened in the lower end of the pipe, the connection being as nearly water-tight as possible. A marble or a round steel ball is placed above the nut, and about 6 inches above it a bar is placed across the pipe to prevent the ball from falling out. When the pipe is dropped into a drill hole water

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[a] Bowles, Oliver, Op. cit., pp. 77–78.

enters through the lower hole, and the ball fitting into the hole acts as a valve and prevents the water from running out while the pipe is being removed.

SUBDIVISION OF SMALLER PIECES PARALLEL WITH BEDDING.

Masses of the less indurated types of sandstone may be split on the bed by cutting grip holes and driving points in them. The term "point" is applied to a particular form of wedge that tapers to a narrow thin edge. In easy splitting rock the points may be placed 1 to 2 feet apart; in tougher rock they may be placed close together in a continuous grip. At some quarries, before the points are inserted, water is poured into the pick holes to clean them out and to make the points hold more firmly.

In the more indurated sandstones pick holes can not be cut readily. It is customary in some quarries to place the block on edge and to split it by sledging on a "sett"—a quarryman's term for a square-faced steel tool—held in position by means of a handle by one man, while another strikes it with a sledge. The block is marked at the ends and is struck successive blows along the line of desired splitting until a fracture is formed.

Blocks of quartzite are usually split by wedging in shallow drill holes. The method employed in quarries near White Haven, Pa., is to drill holes about one-half inch in diameter and 3 inches deep and spaced about 2 feet apart. Small plugs and feathers are driven into these holes with a light hammer. In this particular quartzite, splitting can not be accomplished with equal ease in all planes. On a fractured surface at right angles to the bedding thin white lines appear at intervals. It has been found by experience that splitting takes place much more readily along these lines than in intervening positions.

HOISTING.

MACHINERY.

Derricks and hoists used in sandstone quarries are, in most respects, similar to those used in marble quarries, which have been discussed at length in Bureau of Mines Bulletin 106.[a] The discussion here is confined to certain modifications as observed in sandstone quarries.

Sandstone cuts much more rapidly than marble, and the mass of rock handled by a given number of workmen in sandstone quarries is greater than that handled by a similar number in marble quarries. Consequently, there is relatively more hoisting to be done.

[a] Bowles, Oliver, The technology of marble quarrying: Bull. 106, Bureau of Mines, 1916, pp. 89–92.

It is not economical to hoist at high speed, as too much power is required. It therefore becomes necessary, in proportion to the number of men employed, to have a greater number of derricks at sandstone quarries than at marble quarries.

Most derrick hoists are operated by steam, though compressed air and electric hoists are used to some extent. Where compressed air is employed in winter time it is usually passed through a preheater before it enters the hoist engines.

POSITION OF DERRICKS.

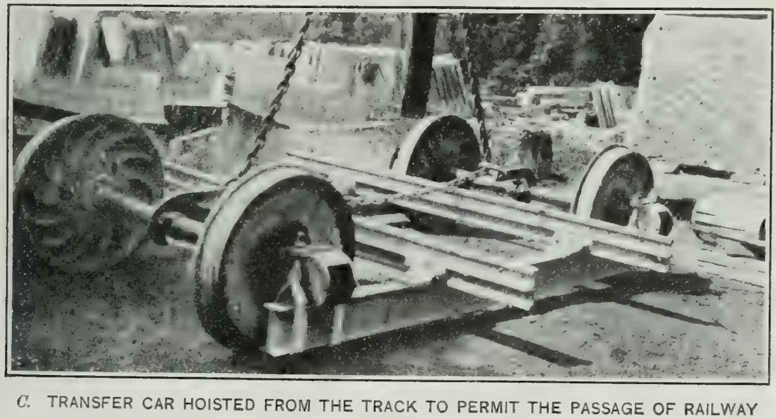
On account of the great mass of rock to be handled, in some quarries it is necessary to move derricks rather frequently. At one of the large quarries near Amherst, Ohio, the mass of rock worked out from one position of the derrick is called a "motion." A "motion" includes the area covered by the radius of the boom, and in addition the area from which the rock may be economically dragged. For most of the derricks employed, the boom radius plus the practical length of drag covers a surface area of 134 by 61 feet. The derrick is not, however, placed opposite the center of this mass, but is situated nearer the free end. The reason for this position is shown in figure 12. The rock is worked out in 8-foot benches, and a space of 1½ feet is lost on every bench on account of the fact that the channeling machine can not cut close to the wall. Thus the free end *A* of the "motion" is not a vertical wall, but is shaped like a gigantic stair, with 1½-foot treads and 8-foot risers. As the "motion" is worked downward, a series of similar steps are formed at the end *B*. Likewise the back face *C* will descend in steps like those of *D*. Thus the upper surface of the quarry "motion" is shifted a distance of 1½ feet toward *A*, and a similar distance toward *D* with every floor removed. A vertical depth of excavation of 200 feet involves, therefore, a shift of about 37 feet in both these directions. Consequently, the derrick is placed nearer to *A* than to *B*. The blocks of the lower beds at the end *A* may lie beyond the practical reach of the derrick *x*, and may be removed by the derrick *y* on the next "motion" to the right.

PORTABLE DERRICKS.

Where the mass of available rock is only a few feet in thickness, derricks must be moved frequently, and consequently should be of such a type that they can be moved from point to point at the expense of minimum time and labor. Plate IV, *A*, illustrates the type of stiff-leg derrick employed in a shallow quarry near McDermott, Ohio. It can be moved the distance required for a quarry "motion" in about two hours. As shown in the illustration, when

A. TYPE OF PORTABLE DERRICK EMPLOYED IN A WIDE AND SHALLOW QUARRY WHERE HEAVY LIFTING IS NOT REQUIRED.

B. AN I-BEAM DERRICK CRANE FOR YARD SERVICE.



C. TRANSFER CAR HOISTED FROM THE TRACK TO PERMIT THE PASSAGE OF RAILWAY CARS.

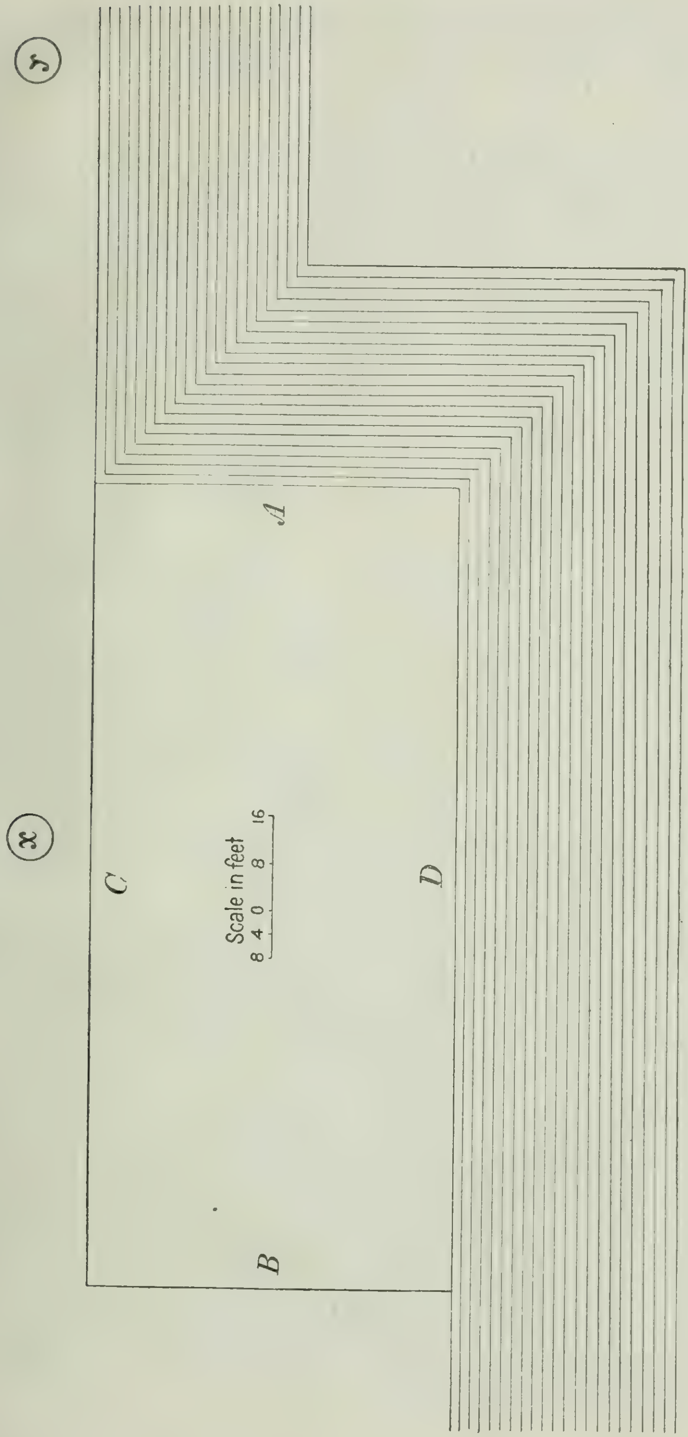


FIGURE 12.—A derrick "motion" in an Ohio quarry, showing position of derrick.

placed in proper position it is loaded with blocks of stone to give it the necessary stability. It can be moved much more readily than a guy derrick, and gives efficient service where heavy hoisting is not required.

In some quarries a stiff-leg derrick is necessary on account of the fact that no means of attaching outside cables are available. In the case of one such derrick observed, the hoist cable between the hoist shed and the derrick passed over rollers about 20 feet above the ground, an arrangement that kept the cable out of the way and rendered it safer than those operating near the ground.

For light hoisting a steam shovel having a boom equipped with a running cable may be used as a substitute for a derrick. Thus, an expensive machine, which otherwise would be idle all summer, is made to render some service.

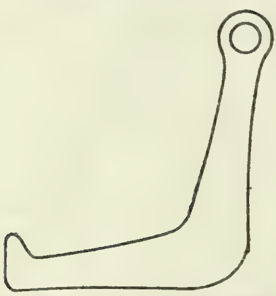


FIGURE 13.—Form of grabhook employed by some sandstone-quarry companies.

CABLE ATTACHMENT.

Grabhooks, chains, and cable slings are used for attachment to blocks of stone, the former being more common. As pointed out in Bulletin 106,[a] chains are of uncertain strength, and are somewhat treacherous; grabhooks are convenient, but less secure than chains or slings in weak rock; cable slings are the safest. Grabhooks have an advantage over the other methods referred to in that the block can be lifted from a position flat on the quarry floor, whereas with chains or slings it must be raised several inches from the floor and blocked up in order to pass lifting apparatus beneath it.

For hoisting heavy blocks one Ohio company employs two pairs of grabhooks, one pair being attached near each end of the block. A form of grabhook used by at least two sandstone companies is shown in figure 13. The flat part between the tip and the bend of the hook presses firmly against the rock surface and relieves a large part of the pressure from the tip of the hook and from the corner of the block. The strain on the hook is less than when it is curved in the ordinary way, and also the block is held more securely.

If chains are employed, a noteworthy method of economizing time and also of relieving the chains of considerable wear and tear is that employed by a Connecticut company. Chains are passed completely around the sandstone blocks, which are then hoisted from the quarry, and when the blocks are placed on flat cars the chains are left around

[a] Bowles, Oliver, Op. cit., pp. 82–83.

them, a separate chain being used for each block. When the blocks are taken to the mill or yard, it is a simple matter to hook into the chain already attached.

TUNNELING.

TUNNELING AS CONDUCTED IN MARBLE QUARRIES.

Tunneling to avoid the handling of heavy stripping is practiced successfully in a number of marble quarries. A preliminary tunnel 6 or 7 feet high is first made by drilling and blasting, the material being removed as waste. Pillars of rock are left at intervals of 60 to 100 feet for roof support. When the preliminary tunnel is completed the rock is quarried in the same manner as an open ledge. The cost of tunneling under favorable conditions is much lower than the cost of removing a heavy stripping or a considerable depth of waste rock. Details of the methods, advantages, and dangers of tunneling in marble are given in Bureau of Mines Bulletin 106.[a]

TUNNELING IN SANDSTONE.

A tunneled sandstone quarry has been observed by the writer at one place only, although one or two other examples have been reported. The quarry observed is situated at Fairmont, W. Va., and is inactive at the time of writing. The overlying rock consists of unsound limestone and shale, material that is not good for a roof. Six or seven openings were made in the bluff, and pillars, irregular in form, size, and distribution, were left for roof supports. The excavation is about 150 by 75 feet in extent, and the ledge of good rock is about 16 feet thick. Some of the poor, inferior beds were first blasted out, forming a preliminary tunnel to give headroom, and in consequence the upper parts of the pillars are of soft and unsound material. Considerable rock has fallen from the roof during the past two years. Rock falls occur in the springtime, and are seemingly caused chiefly by the freezing of water in the joints. Tunneling in this quarry is said to have been successful and resulted in no accidents.

It will be noted that at least two conditions are unfavorable, the first being the unsound nature of the stone and the second the limited thickness, 16 feet, of available rock. Successful tunneling under such unfavorable conditions promises well for the success of the method in heavy deposits of sound rock.

ADAPTABILITY OF SANDSTONE FOR TUNNEL ROOF.

In the quarry mentioned above the tunnel roof was of limestone and shale and not of sandstone, consequently no tunnel roofs con-

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[a] Bowles, Oliver, Op cit., pp. 84–87.

sisting of sandstone have been observed. The adaptability of sandstone for tunneling remains to be demonstrated. Some quarrymen think that sandstone is inclined to spall off more readily than marble and that tunnels projected into it would introduce an element of danger to quarry operators. The nature of sandstone ceilings in natural tunnels may offer some suggestions. It is stated by Maj. J. S. Sewell,[a] who has visited the Great Mammoth Cave in Kentucky, that the ceilings of many of the corridors are of sandstone, and that the process of spalling has given to the ceilings an arched shape which appears to be fairly stable where not exposed to the ravages of frost. This suggests that a tunnel ceiling cut into an arched form may be much safer than a flat ceiling.

SANDSTONE QUARRIES BEST ADAPTED FOR TUNNELING.

Quarries in which the beds of serviceable stone are overlaid with an excessive thickness of waste material, part or all of which consists of inferior rock, are those best suited for successful tunneling. Necessary conditions for safe and efficient tunneling demand the presence of a reasonably sound roof of sufficient thickness to insure against collapse, and one that will also permit a fairly wide spacing of pillars. In order to fulfill these conditions it may be necessary to drive a preliminary tunnel into good rock, thus wasting a mass 6 or 7 feet thick over the entire area of the tunnel. If, however, there is a heavy band of inferior though reasonably strong rock, the preliminary tunnel may be driven into the inferior material and thus conserve the underlying sound stock.

Seemingly tunneling would afford a great saving in quarries situated on steep bluffs, like those near Empire, Ohio. In this region the disposal of stripping by tramway and cable cars to points some distance from quarries and beyond transportation lines is expensive. Moreover, quarries on steep hillsides almost invariably meet with a greatly increasing depth of overburden as the face is worked back into the hill. A depth of 60 feet of combined waste rock and soil has been noted in quarries of this type, and with a further advancement of the quarry face this depth would be increased. It is evident that the cost of removal of such a depth of waste material is almost prohibitive. Under present conditions, the good rock beneath the excessive overburden is unavailable, as development must proceed laterally. If sufficient thickness of sound material is present to form a strong roof, and if the depth of underlying good rock is 30 feet or more, the author is of the opinion that tunneling could be conducted successfully in such deposits, and that the cost of quarrying

[a] Personal communication.

would thereby be reduced to a much lower figure than can be maintained under present conditions. It is believed that the risk from roof falls would be less than that to which quarrymen are now exposed where steep walls of loose rock or soil are adjacent to the quarry pits.

It would be wise for those contemplating the adoption of tunneling methods to visit the tunneled marble quarries of Alabama and Vermont. It must be kept in mind, however, that for any given equipment and number of men employed, the amount of rock handled in a given time is usually much greater in a sandstone quarry than in a marble quarry. As a consequence the size of the tunnel must be planned in accordance with the probable extent of operations.

QUARRY DRAINAGE.

Occasionally the sandstone quarryman is fortunate enough to have automatic quarry drainage. Hillside quarries usually drain readily to the lower levels of surrounding regions. Other quarries may be underlaid by permeable beds which permit the water to drain away readily.

If surface water only enters the quarry, little pumping is necessary, except in times of heavy rain. If, however, springs are encountered, the flow of water may require almost constant pumping.

If the low-water level in the quarry is higher than the drainage basin outside the quarry, and if the rock ridge over which the water must pass is not more than 30 feet higher than the low-water level in the quarry, a siphon may be used. The siphon method of water removal is employed in a quarry near Hummelstown, Pa., and in a number of bluestone quarries.

Various methods are employed for pumping water from quarry pits; piston pumps operated by steam, electricity, or gasoline engines, centrifugal pumps, and pulsometers have been observed.

YARD SERVICE.

DEFINITION OF YARD SERVICE.

The term "yard service" in the following pages includes rock transportation from the quarry bank to the mill or finishing plant when such is present, and also transportation of the finished product to the railway lines or navigable waters, by which it is transported to its destination. In the case of quarries which have no finishing plants connected with them, yard service refers to the transportation of rock from the quarry to the main transportation lines.

YARD DERRICKS AND OTHER HOISTING APPARATUS.

Some rock-finishing plants are so conveniently situated with respect to quarries that yard derricks can take the rock from the quarry bank and deliver it direct to the finishing plant. Where not so conveniently arranged, quarry or yard derricks are almost invariably used to load rock onto cars for transportation to finishing plants. When finishing processes, such as shaping grindstones, or splitting and trimming curbstones, are conducted out of doors, yard derricks are commonly employed to handle the heavy rock masses. Yard derricks are also employed to load gang cars, to pile the finished product in the yard, or to load it ready for transportation. In one Ohio mill the derricks for loading and unloading gang cars are belt driven from the mill countershaft.

A convenient derrick for handling material of small size is the I-beam derrick crane as used in one southern Ohio yard. A small traveling crane runs back and forth on the I-beam type of derrick boom. The boom may be swung in a complete circle around the mast, but can not be raised or lowered. In Plate IV, *B*, the traveler and boom are shown in the foreground, and an entire derrick of similar type in the background.

Locomotive cranes are employed in many places to do the work of derricks. They have the advantage of being self driven, and are especially useful in handling stock of small size. In the Medina region of New York boxes of paving stones are lifted and dumped into open railway cars by this means.

Overhead traveling cranes are commonly used to serve mills, and may be extended to give yard service over considerable areas.

SMALL QUARRY CARS OPERATED ON LEVEL OR NEARLY LEVEL TRACKS.

Blocks are commonly loaded on small quarry cars and conducted to their destination by gravity, or by horse, mule, or cable haulage. In many places tracks are so arranged that loaded cars run on a gentle down grade, and the empty cars can be returned by hand. If the cars must be transported on the level or up grade, horses, mules, or cable hoists are commonly used. At one crushed-stone quarry the quarry cars are hauled part way to the crusher by horses, and the remainder of the distance they are taken up an inclined tramway by means of a heavy endless chain having hooks projecting upward at intervals.

In crushed-stone quarries, where great masses of rock are thrown down by blasting, it is difficult to keep tracks in repair in the vicinity of the quarry face. Where conditions are favorable an overhead cableway hoist might be substituted. Such equipment is always out of the way of falling rock.

GRAVITY CABLE CARS.

Where quarries are situated at high levels gravity cable cars are commonly employed to take the rock down to mills or transportation lines. The following types of tracks have been observed: Two-rail track, that is, a single track; single track below the center switch, and a three-rail track above; three-rail track throughout the entire length; four-rail track, that is, a double track. With a single-track system a loaded car is let down, unloaded, and the empty car hauled back with a hoist engine. With the other systems mentioned a car is attached to either end of the cable, which is controlled by a brake on a drum, and the empty car is hauled upward by the descending loaded car. At one Ohio quarry standard railway cars are employed, but usually the cable cars are much smaller.

LOCOMOTIVES AND STANDARD CARS.

In quarries of considerable size rock is usually hauled from quarry to mill, and from mill to main transportation lines, or directly from quarry to main lines, in standard cars by locomotives operated by the quarry company. Small locomotives termed "dinkeys" are in common use. Smaller quarries may have railway sidings, but no locomotives, the cars being hauled as occasion demands by the railway company operating on the line that the switch joins. Traveling cranes are used to some extent for haulage.

TEAMS.

Small quarries situated in regions where transportation by other means would require too much capital usually depend on wagons hauled by teams for rock transportation. Aside from bluestone quarries not many sandstone quarries depend upon such equipment, as it is slow and expensive, and the quantity of rock handled is limited.

SANDSTONE SAWMILLS AND FINISHING PLANTS.

MANUFACTURING IN CONNECTION WITH QUARRYING.

Although much block sandstone is sold to dealers in large centers of population, nearly all quarries that produce stone for building uses, or for grindstones, curbing, or flagging, with the exception of the bluestone quarries, have mills or finishing plants connected with them. The combination of sawing or otherwise finishing with quarrying has certain definite advantages. The quarryman understands his rock, he knows its peculiarities and defects, and knows how it should best be worked in order to minimize its weaknesses. By sawing in accordance with unsoundness, or in such a manner as to

give the best surfaces possible on blocks of stone containing defects of coloring or composition, the proportion of waste is much lower, and the serviceable stone may possibly be placed in a higher grade, than when the blocks are sawed without regard for such structures. Furthermore, the finishing of the stone in the vicinity of the quarry removes the necessity of paying transportation charges on the material that is wasted in manufacture.

SITUATION OF PLANT.

Where possible, mills or other finishing plants should be placed convenient to the quarry. In some cases blocks are loaded directly on gang cars by the quarry derricks. For a quarry situated at a high elevation it may seem advantageous to place the finishing plant at the foot of the hill, as at Sherrodsville, Ohio. In certain other quarries situated at high levels—as, for example, those near Empire, Ohio—finishing is done at the quarry level and the finished product is transported to the foot of the hill by cable cars.

The situation of such plants depends also on the source of power and the situation of the power plant. It is wise to place the plant where it demands a minimum transformation of power from one form to another. Thus, if water power is available, connecting the turbines directly with the mill is simpler and much less expensive in first cost and maintenance than transforming the water power into electric power and driving the mill by electricity. If other circumstances permit, the mill should, therefore, be placed where such direct connection is possible. If electric generation is necessary for other purposes, it may, however, be advisable to use electricity for driving the mill also, and under such conditions its situation will be governed by other factors.

SAWING SANDSTONE.

POWER.

Water, steam, and electric power are employed to operate saw gangs. Direct water power is simple and requires less expensive equipment than hydroelectric power. Direct steam power is employed in few places, as usually electricity is required for quarry operations, and therefore an electric generating plant is necessary.

Electric power is applied to saw gangs in a variety of ways. In some mills individual motors are used for each gang, and in others one motor drives a group of 6 to 12 gangs. In the latter case a gang may be stopped by shifting the belt to an idle pulley. Certain advantages and disadvantages of the two methods may be enumerated.

The use of individual motors makes easy the repair of motors without tying up the entire mill. On the other hand, the first cost of 10 individual motors is greater than the cost of 1 motor

of sufficient size to drive 10 gangs. Moreover, the most economical speed of a small motor is higher than that of a large motor, and as gangs are operated with a relatively slow motion a greater reduction in speed is required for the individual motors than for the single motor of larger size. The greater the reduction in speed that is demanded the greater are the losses through friction and wear.

Where individual motors are used, the crank shaft of the gang may be gear driven or belt driven. It is claimed that the vibration and jarring of gears has an injurious effect on motors and that on this account belts are to be preferred. Plate V, *A*, illustrates a large Ohio mill with individual motors and gear-driven gangs.

SAW GANGS.

Gang frames are of various widths and lengths, depending on the sizes of the blocks sawed. Gangs in a single mill may be of various widths to accommodate blocks suitable for different purposes. Where there is great variation in the length of the stock, gang frames of different lengths are required. A sliding head has lately been devised which permits adjustment of a gang frame for length.

Two types of gangs are in common use, the rope-feed and the screw-feed. The rope-feed gang is suspended by means of steel cables attached to counterbalance weights. The weights may be adjusted in such a manner that the gangs are allowed to exert any desired downward pressure of the saws on the rock. Thus a constant pressure may be maintained, and the rate of cutting will be governed by the hardness of the rock. If a hard, flinty mass is encountered, the rate of sawing is appreciably reduced until the obstruction is cut through.

Screw-feed gangs are fed downward by gears, and, although the rate of downward motion may be regulated, the device is not self-adjusting. If a flinty mass is encountered, the rate of sawing is not automatically reduced, and if the saw is overcrowded, the blade is inclined to run to one side, with consequent production of an uneven rock surface. The screw feed is employed on nearly all modern gangs.

It is important that all bearings be properly capped to keep them sand-proof. Any looseness occasioned by wear should be taken up so that the shafts run in the bearings without play. Inefficient service is rendered if saw blades do not run true. The fault may be in the play of the shafts in the bearings or in improper setting of the blades. With improper adjustment of gang bearings or blades a side motion may accompany the backward-and-forward motion of a blade, and as a result the saw cut may be two or three times as wide as it should be, obviously involving waste of power, time, steel, and rock.

DEVICE TO PREVENT EDGES OF BLOCKS FROM CHIPPING OFF.

When, in the course of sawing, the blades approach the bottom of the block there is danger of the lower edge of the block chipping off. If the lower face of the block is a sawed surface, the chipping off of edges may seriously mar the finished product. A simple device introduced by one Ohio company prevents such chipping of the edges. One end of the block is raised one or two inches higher than the other end, so that the saw reaches the bottom of the block at one end before it reaches the bottom at the other end. With such an arrangement the blade intersects the lower face at a long angle and the danger of chipping the edges is minimized.

ABRASIVES.

Sharp sand is used commonly as abrasive in sawing. It leaves a smooth surface and causes no staining of the rock. Although crushed steel or steel shot cut 25 to 50 per cent faster than sand under similar circumstances, there are some disadvantages in their use. They leave a much rougher surface than sand, and if the rock is to be used for structural purposes the surface must be sand-rubbed, whereas if sand alone is used as abrasive this process may be omitted. If the rock is porous, there is danger of stains resulting from iron rust, though this is overcome to some extent by mixing lime with the steel. Where the stone is to be used for such purposes as curbing and flagging a steel abrasive is very satisfactory. A mixture of sand and steel is commonly used.

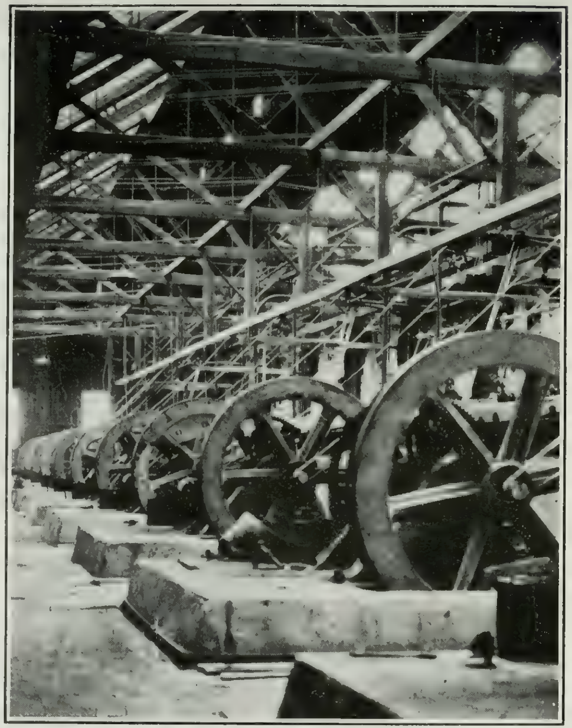
In a Michigan quarry some years ago steel shot were crushed into soft iron blades by passing them between rolls, and thus a saw was produced with the abrasive contained within it. No information has been obtained of the success of the experiment, but the suggestion may be of value.

One Ohio company tried carborundum powder as abrasive, and by this means increased the rate of sawing from 6 inches to 26 inches per hour. At first the method appeared to be an unqualified success, but it was soon found that the carborundum powder was rapidly pulverized to a condition of fineness that rendered it ineffective. Thus, although the rate of sawing is high, the cost of the abrasive is also high.

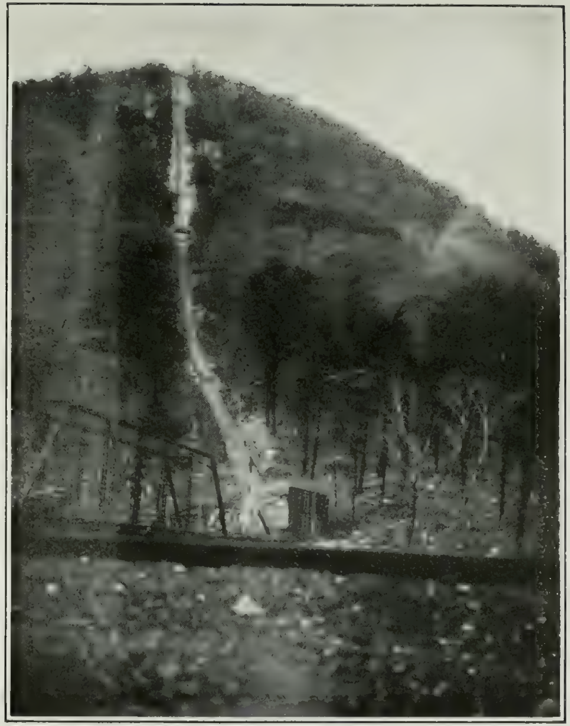
SAND PUMPS.

Centrifugal sand pumps are in common use for elevation of the abrasive to a point above the gangs, from which it may be distributed to the saws for repeated use.

When the concrete bed beneath the gang is too flat, difficulty is sometimes experienced in getting the crushed steel back to the pump



A. A SANDSTONE SAWMILL WITH INDIVIDUAL MOTORS AND GEAR-DRIVEN GANGS.



B. CABLE-CAR TRACKS AT A GANISTER QUARRY NEAR POINT VIEW, PA.

well for elevation. A device employed by one millman to assist movement of the steel is a belt made of discarded belting and provided with crossbars, by which the steel is carried back to the pump well.

An air lift is now employed successfully in a number of places. For raising sand in water a well of sufficient depth is required to have about one and one-half times as much pipe submerged as above the water level. A jet of compressed air enters at the bottom, which agitates and aerates the water, causing it to rise in the pipe. The successful use of an air lift with crushed steel has not yet been demonstrated so far as is known. It is evident that a greater volume of air and more agitation would be necessary on account of the steel having a higher specific gravity than the sand. The great advantage of the air lift consists in its simplicity and the absence of moving or rotating parts, which are rapidly worn out by sand and especially by crushed steel.

At some mills no pumps are employed, the abrasive being shoveled on by hand. Where river sand is obtained near by, it is commonly allowed to escape after one use.

RATE OF SAWING.

The rate at which saws sink through sandstone blocks depends on a number of factors, such as length and number of blades, kind of abrasive used, and hardness of the stone. Where gangs contain 10 to 15 blades and are employed in sawing average sandstone blocks 5 to 7 feet long, they sink at the rate of 3 to 8 inches per hour when sand is used and 6 to 12 inches per hour when steel is used. The rate is governed also by the nature of the product. In rough material, such as curbing, saws may be crowded to their maximum capacity, but when building blocks are being sawed such crowding is not permissible, as it may produce irregularities on the surface.

The more indurated sandstones or quartzites can not be sawed profitably on account of their extreme hardness. When an attempt was made to saw the White Haven, Pa., quartzite parallel with the bedding, the saws would run in the softer reeds and then bind.

TRANSFER AND GANG CARS.

Gang cars, which take the place of the old-fashioned timber saw beds, are employed almost universally in sandstone sawmills. Transfer cars are used at Berea, Ohio; at some of the mills at Amherst, Ohio; at Fulton, Ohio; at Eagle Harbor, N. Y.; and at a number of other places. At some mills, where efficient service is rendered by derricks or traveling cranes, transfer cars are not employed. The writer is convinced, however, that the transfer car is an advantage in

any case, as otherwise the gang is kept in idleness during the time of unloading and reloading the gang car. One company in Ohio found that the installation of a transfer-car system reduced the time during which the gangs were idle to one-third of what it was before the system was introduced. Derricks are employed for loading and unloading at this quarry.

At one sandstone plant in Ohio a railway siding to the quarry passes in front of the mill and is utilized for a transfer-car track. During the time when railway cars are being moved on the siding the transfer car is removed from the track with a derrick, as shown in Plate IV, *C*. Plate IV, *C*, also illustrates a simple and efficient type of transfer car.

LOADING EQUIPMENT.

For most small mills derricks are employed for loading gang cars. At the larger mills overhead traveling cranes are found to give the most efficient service. They may be extended to serve adjoining mills, storage yards, etc.

OTHER SAWS.

For making third and subsequent cuts, saws other than gang saws are commonly used. Diamond saws have been tried in some Ohio sandstones, but have given poor service. Circular saws with carborundum teeth have given satisfactory service even in sandstones indurated sufficiently to make feasible their use as paving stones. A blade mounted with diamond teeth and set in a straight-cut gang frame is used to some extent.

RUBBING BEDS.

Plants that are equipped for the production of building stone require rubbing beds, as many structural blocks require sand rubbing in order to give them smooth, even surfaces. Where sand is used as an abrasive in sawing, the resulting surface is commonly so smooth that bed rubbing is unnecessary. Where steel is used, however, the irregularities on the surface must be removed.

A simple device is employed by a Pennsylvania company for returning sand to rubbing beds. A 2-inch iron pipe is set in bearings, with one end over the rubbing bed, and is rotated slowly by means of a belt on a pulley. It is nearly horizontal, though slightly lower at the end toward the bed. At the opposite end is a second pipe about 3 feet long projecting at right angles. The latter pipe is curved at the outer end in the direction of revolution, and as it revolves it dips into a trough into which sand and water drain from the bed. As the pipe revolves, the sand and water entering

it run down through the rotating axis and are thus returned to the bed.

PLANERS.

Planers are used where such forms as cornices, moldings, and curbstones are shaped. The more common type employed is a Scotch reversible-head planer. In indurated sandstone difficulty is experienced in getting a tool that will stand the work required of it, as the heat generated in the process of planing burns the steel. Overheating of the tool can be prevented in very hard sandstone if a stream of water of sufficient size is directed on the tool.

MANUFACTURING CURBING.

Large blocks for the manufacture of curbstones are commonly drilled and split into smaller sizes with plug and feather. The final

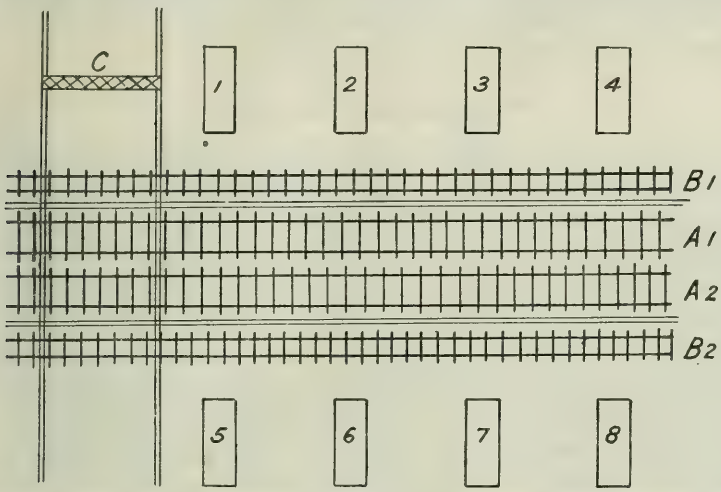


FIGURE 14.—Plan of an Ohio curbing mill. A_1, A_2, depressed railway tracks; B_1, B_2, hand-car tracks. *C*, overhead traveling crane; *1* to *8*, planers.

splitting into rough curbstones is conducted in different ways, depending upon the ease of splitting. In split rock a line is made and notches cut out with a pick at intervals along the line. It is then marked along the line of holes with a chisel-edged tool and hammer, and split with a bull wedge and sledge. In rock which splits with greater difficulty plugs and feathers may be used. Massive rock with no apparent rift may be sawed into curbing blocks.

PLAN OF CURBING MILL.

At some of the larger Ohio sandstone quarries, mills are equipped for the production of curbing only. One such mill is so conveniently arranged for rapid operation that the floor plan, shown in figure 14, may offer useful suggestions. Two depressed railway

tracks, A_1 and A_2, pass down the center, and the planers, *1* to *8*, are placed four at either side of this depression. Four overhead tracks pass over the railway tracks, each being in line with one pair of planers. Pneumatic cranes operate on these tracks for handling curbstones. The blocks are placed on cars by means of the overhead traveling crane *C* shown at the end of the mill in the figure; or in some cases the cars may be loaded by means of yard derricks. Large blocks are split to proper width and length for curbstones, but thick enough to make four or five of them. The blocks are marked ready to split, then placed on the cars, where the final separations are made. When the cars enter the mill, curbstones are taken from them one at a time by the pneumatic crane, placed on the planer bed, planed to shape, and returned to the same car. In order to transfer stone from one part of the mill to another small hand-car tracks are provided at either side between the planers and the center depression, as shown at B_1 and B_2 in the figure.

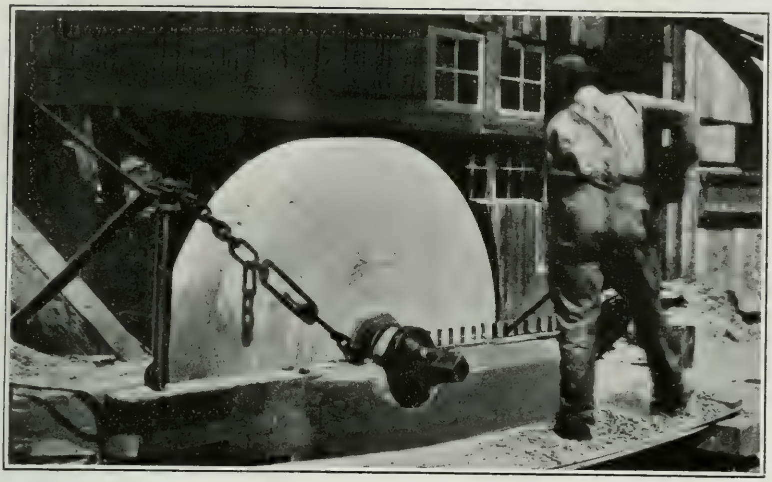
FINISHING GRINDSTONES.

Grindstones are turned to proper form by first cutting square center holes and then placing them on shafts and shaping them with steel tools as they rotate. The smaller rough stones which are not circular in form are marked at each side for their proper circumference by holding pointed tools against their sides in proper position and allowing them to cut grooves. The grooves are not cut very deep, as this would involve the danger of masses of rock flying from the stones, impelled by centrifugal force. The outer masses are broken off with hammers while the stones are at rest.

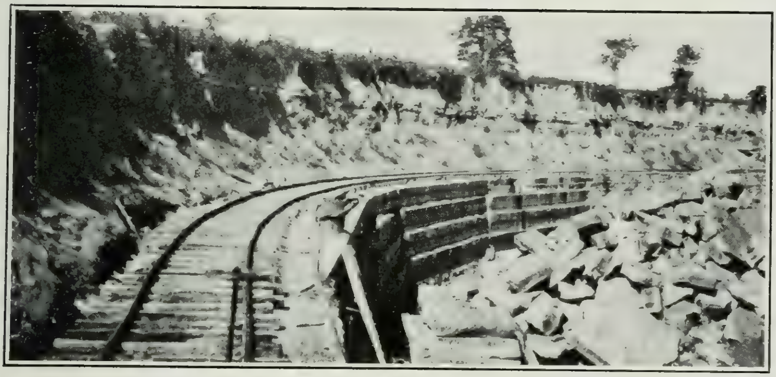
The larger stones are usually shaped into circular form before they are placed in the lathes. In southern Ohio they are cut out in the quarries with circle-cutting drills, while in northern Ohio they are quarried out as cubical blocks and scabbled to circular form. The faces and sides of the stones are trimmed by holding a bar against them as they rotate. Plate VI, *A*, illustrates the method of shaping a 7-foot stone. The row of upright pins on the timber base are for the purpose of holding the cutting bar in various positions. The workmen may stand on either side, and if two men are employed both sides of the stone may be trimmed simultaneously.

Grindstone lathes are operated by steam, electricity, gasoline, or natural-gas engines, the choice of power depending upon relative costs and availability.

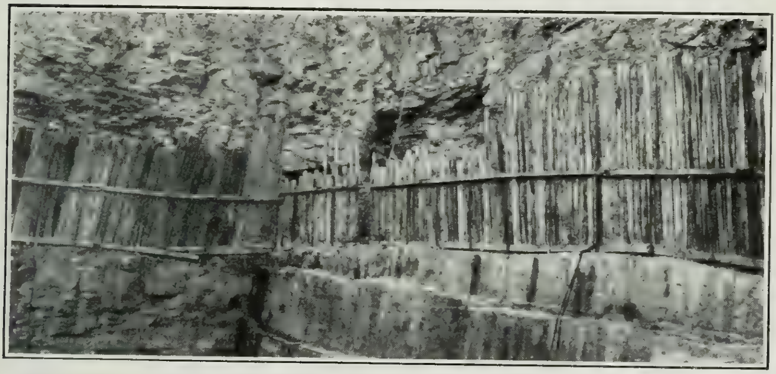
Most lathes are provided with suction pipes in the pits to carry away the dust, and thus reduce the danger of its injurious effects upon workmen.



A. METHOD OF SHAPING A 7-FOOT GRINDSTONE IN A LATHE.



B. A CURVING QUARRY FACE WHICH, WHEN WORKED BACK, RESULTS IN THE PRODUCTION OF ANGULAR BLOCKS.



C. WOODEN BARRIER TO PREVENT FRAGMENTS OF OVERBURDEN FALLING INTO QUARRY.

CUTTING.

A certain amount of hand cutting is necessary, especially in plants where building stone is produced. It involves rough work such as the cutting of rock-face ashlar from irregular waste blocks, and also the finer carving required for decorative effects. In some cases a surfacing machine such as the patent axe is used successfully. Different sandstones require different methods of handling and different tools. For example, it is found that a light and springy tool "plucks" less than a heavy tool in the fine-grained sandstones of McDermott, Ohio. The best methods of cutting and the most efficient tools to use for any given type of sandstone can be determined only by experience.

CRANE SERVICE IN FINISHING PLANTS.

Rapid handling of material in finishing plants depends upon efficient crane service. For a plant which handles both light and heavy blocks, as is the case with most finishing plants, a light and rapid crane is desirable for handling small pieces, and a slower and heavier crane for the larger blocks. The handling of numerous small blocks by a crane capable of lifting heavy masses involves loss of time and power.

Pneumatic cranes give very efficient service for handling smaller pieces such as curbstones. In at least two curbing mills in Ohio a pneumatic crane of 2,000-pound capacity serves each planer, and additional cranes are employed for yard service.

WASTE IN SANDSTONE QUARRYING.

DEFINITION OF WASTE.

The term "waste" is subject to varied definitions. Some quarrymen define it as that part of the quarried rock which can not be utilized for any purpose whatever. Others include with waste those by-products which may be disposed of at a price which will not compensate for the cost of production. It is evident that no quarryman will, if he can avoid it, quarry stone from which he can not realize a sum sufficient to pay the cost of operation, and the production of such rock is occasioned only by the necessity for its removal in order that stone of better quality may be available. Such inferior material may properly be classified as waste, and the term "waste," as used in the following pages, includes, therefore, those portions of the quarried rock which are lost in manufacture, thrown away, or utilized as by-products which, on the average, bring returns smaller than the cost of production.

CAUSES OF WASTE.

Waste in sandstone quarrying may be attributed to a variety of causes, many of which are due to natural imperfections in the rock. Waste is also caused by improper methods of separating the rock masses from the quarry ledge.

ROCK IMPERFECTIONS.

DEFECTS IN JOINTING.

In many quarries joints are straight and regular, and occur in a parallel system, or in two systems at approximately right angles, conditions that favor economical quarrying if the joints are spaced at convenient distances to permit the production of blocks of reasonable size. If the joints are too closely spaced, the blocks available will be too small to command the best price on the market. The most economical spacing depends on the use for which the stone is best adapted, and conditions of spacing that might be quite suitable in one quarry would be unsuitable in another.

In other quarries joints may be curved and uneven and intersect at oblique angles. When this is the case angular and uneven blocks are quarried, and much rock is lost in reducing them to suitable shape. Joints may occur in closely spaced groups, all the rock within the boundaries of such groups spliting out in thin slabs which are usually curved, fractured, and of little or no economic value. "Casing" is a local term applied to thin slabs that split out between closely spaced joints.

Blind seams or dry seams appear as fine lines on the rock surface. In some sandstones circulating water containing silica in solution deposits silica in the seams, and thereby cements the rock until it is practically as strong as though no seam ever existed. Usually, however, the rock parts easily along such planes. Commonly they are sufficiently open to permit oxidation of the rock adjacent to their walls, making them appear as stained lines across the rock surface. They are prolific sources of waste in sandstone quarries.

DEFECTS IN BEDDING.

Open bedding planes at moderate intervals greatly facilitate quarrying. If, however, bedding planes are less than 5 or 6 inches apart, the rock will probably be useless, although, if true and even planes occur, good slabs may be obtained where open beds are only an inch or two apart. When such planes are ill defined, are a fraction of an inch to 1 or 2 inches apart, and irregular, the rock must be classed as waste material. Thin bedding may be due to processes of deposition such as sudden and frequent changes in the nature

of the material deposited; or it may be due to processes of surface weathering which tend to open up the bedding planes. The upper part of most of the Ohio deposits is thin-bedded to various depths, attaining a maximum of about 35 feet. This thin bedding is thought to be due to conditions of deposition, although surface weathering has undoubtedly emphasized it.

Thin-bedded deposits are not always the upper beds of sandstone ledges; they may be interbedded with heavy and sound beds. Conditions of deposition obviously account for this state. Thin bedding accounts for a considerable part of the waste in some localities.

Where the surfaces of open beds are in straight, uniform, smooth planes, as in some quarries near Berea, Ohio, the upper and the lower surfaces of the blocks obtained require no scabbling, and therefore no material is lost in this process. Bownocker [a] gives a remarkable example of uniform bedding planes in southern Ohio sandstone. In other localities, as, for example, in certain beds of the Kettle River sandstone of Minnesota, the bedding is wavy and uneven, and the irregularities on the blocks of stone obtained from such beds must be scabbled or sawed off, with consequent waste of stone.

In certain deposits bedding planes are not all parallel. The thickness of a bed lying between two converging planes varies from point to point, and blocks obtained from such a bed lack parallelism between their upper and lower faces. The forms into which sandstone blocks are shaped are with few exceptions parallel faced, and it is therefore obvious that a certain amount of waste must result in cutting nonparallel-faced blocks into parallel-faced forms.

Cross bedding in sandstone may result in uneven or inclined bed splitting, and nonuniform blocks will result. The removal of irregularities will, as in the instances recorded above, involve waste of stone.

DEFECTS IN TEXTURE AND STATE OF AGGREGATION.

Most fine-grained sandstones are more desirable than those of coarser grain, as they are better adapted for cutting and carving and are usually of low porosity and of attractive appearance. Coarse-grained sandstone may, therefore, be of low grade, and may even be classed as waste. For most purposes for which sandstone is used it is desirable that the grain size be uniform. The stone may be so pebbly that it may be classed as conglomerate, and most conglomerates can be utilized only as crushed stone for riprap or the roughest of building purposes. Pebbles in sandstone may break out, leaving a pitted surface, or the surrounding material may fall away first, leaving the pebbles as protuberances on the surface. The appearance of

[a] Bownocker, J. A., Building stones of Ohio: State Geol. Survey, ser. 4, Bull. 18, 1915, p. 139.

a rock surface which shows marked variation in size of grain is usually unattractive. Nonuniformity of grain size may therefore result in many blocks being thrown on the waste heap.

The individual grains of a sandstone may be cemented together insecurely, and the rock may be so friable or easily crumbled as to be useless for structural purposes or for making abrasives, such as grindstones or whetstones. It may be noted, however, that some rather friable stones harden greatly upon exposure to the atmosphere.

Friable beds may occur in ledges that have well-cemented beds above and below them and may cause a high percentage of waste. Usually, however, a condition of extreme friability is confined to surface beds where the cement has been lost by weathering or is characteristic of entire ledges where geologic conditions have not favored the process of cementation. Rocks in the latter condition can scarcely be classed as quarry waste, inasmuch as they are all waste as regards uses requiring reasonable hardness, and therefore quarrying of them should never be attempted.

On the other hand, the grains may be cemented together so firmly that the rock is extremely hard and has the appearance of massive quartz. Although such rocks, termed "quartzites," are probably the most durable of any now in use, the cost of production may be prohibitive on account of the difficulty in quarrying. Excessively hard beds may therefore be classed as waste. Such indurated beds do not, however, occur commonly in quarries in which the principal rock mass is of moderate hardness. Conditions of cementation have usually been constant over considerable areas and for long periods of time, and as a consequence the state of aggregation of sandstone tends to be fairly constant throughout an entire ledge of rock of the same geologic age. Just as in the case of the extremely friable rock, the quartzites commonly constitute entire ledges. If their condition is such that they can not be worked profitably, they are to be classed as unavailable material rather than as waste.

In the preceding discussion conditions of cementation have been considered in their relation to entire beds or to entire deposits. A condition that involves more serious consequence in many deposits is nonuniform cementation in different parts of the same bed. Occasionally small masses are found in which the grains are poorly cemented. They are, therefore, more friable than the surrounding material and may crumble away, leaving hollows or depressions in the surface. Their presence also reduces the crushing strength of the rock. Again, certain masses may be cemented more firmly than the surrounding blocks. They constitute the so-called "hardheads" or "niggerheads" that quarrymen deplore. It is probable that some of them are in the nature of concretions. They not only result in waste

of material, but they reduce the rate of channeling, and may cause the channel steel to take a crooked course.

The ideal state of aggregation for building stone is a condition of uniform cementation throughout the rock mass, the degree of cementation attaining a proper balance between workability, which controls in part the cost of production, and induration, which is the chief factor of durability. For other purposes to which sandstone may be applied, as, for example, the making of pulp stones or grindstones, a certain definite state of cementation is demanded, and little latitude may be allowed in seeking rock of more easy workability.

POROSITY.

Porosity bears a more or less intimate relationship to state of aggregation. Friable sandstones usually are lacking in cementing material, intergranular spaces are incompletely filled, and therefore the rock is porous. Indurated stones are, on the other hand, usually of low porosity on account of the pores being filled with cementing material. Most sandstones are somewhat porous. Absorbed water in the pores may by freezing destroy the rock. A high percentage of porosity is not in itself, however, an indication that the rock will disintegrate readily by freezing. As pointed out by Buckley,[a] the size of the pores has an important bearing on the rate of disintegration. Large pores give up their contained water readily, and hence rapid or serious injury by frost action may not result. Small capillary pores will, however, give up the water contained in them less readily, consequently the effects of frost will be more disastrous. In judging the probable effect of porosity, therefore, one should observe the size of pores as well as the percentage of porosity.

Not only are porous stones liable to disintegration by frost action, but they collect dust and dirt, and therefore darken rapidly.

INJURIOUS CONSTITUENTS.

DESIRABLE AND UNDESIRABLE CONSTITUENTS.

Some sandstones are of exceptional purity, consisting almost entirely of silica. Others contain in addition to silica grains of feldspar, mica, hornblende, or other minerals that were present in the parent rock or rocks from which the original beds of sand came. Calcite, clay, or iron oxides may be present as cementing materials. Most of the constituents are usually not undesirable, but occasionally there are found in certain deposits or in certain beds of a deposit mineral grains of a kind that impair the quality of the stone for

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[a] Buckley, E. R., Building and ornamental stones of Wisconsin: Wisconsin Survey Bull. 4, 1898, pp. 20–25.

certain purposes. A limited amount of impurities may be permitted in stone designed for flagging or curbing, but for structural uses for which attractive appearance is demanded, such imperfections may not be tolerated. The more important injurious constituents of sandstones and their effects on the quality of stone are described in the following paragraphs.

IRON COMPOUNDS.

Many sandstone blocks are thrown on the waste heap because they contain rusty bands, streaks, or spots. Such color variations are due to unequal distribution of iron compounds throughout the rock mass. In some quarries the variation in color may be due to the presence of varying proportions of iron compounds of the same kind. Thus 3 per cent of hematite will give a decidedly deeper red color than 0.25 per cent of the same material. Variations in color from one bed to another are usually due to such variations in the quantity of iron present, although in most cases the same iron compound is present in the various beds.

Rusty streaks and spots are, however, usually due to the presence in certain places of iron compounds that are different from those in the main rock mass. The golden or brassy yellow iron sulphides, pyrite, and marcasite usually occur in streaks or spots and, by oxidation, form rusty stains. It is the oxidation of various compounds that causes the unsightly streaks and spots so much deplored in many building stones. The iron sulphides may first oxidize to iron sulphate and may combine with aluminum compounds if such are present in the sandstone, and appear on the surface as a white efflorescence. Iron compounds when in stable form, such as ferric oxide, if evenly distributed throughout the rock mass in small amounts, are not to be considered as defects, and may be rather desirable. The attractive buff, brown, or reddish-brown colors of many sandstones are due to the presence of iron oxides.

All the iron content is commonly not in the most stable form as it occurs in the rock ledge deep below the surface. The iron may be present as iron carbonate, forming a cement between the sand grains. On this account sandstones commonly change in color after exposure to the air, such change being brought about by oxidation of the various ferrous compounds to ferric forms. A good illustration is to be found in the sandstones of McDermott, Ohio. The lower beds are blue-gray in color; higher up they are gray; and the upper beds are buff. The various colors represent varying stages in oxidation of the iron compounds, those nearer the surface receiving a greater supply of oxygen and thus altering more rapidly than the deeper beds. Structures made from sandstone of the lower blue-gray beds will

gradually change in color to buff, though the process may require many years.

CLAY.

Clay is usually regarded as a deep-water deposit, whereas sand is deposited near the shore. In many places, however, they overlap and form alternating beds, or may be intimately mixed, especially where rivers have carried down clays and deposited them irregularly on a sandy bottom. When clays are firmly consolidated they form shales. Many sandstones, therefore, have shales associated with them.

Where pure sandstone beds alternate with shale beds the conditions may not be undesirable, as the shale bands may constitute open bedding planes which greatly assist quarry operations. This condition prevails in one sandstone quarry in Minnesota and in several Ohio deposits. If the clay or shale beds are thick, the removal of the waste material may be a matter of some consequence.

Occasionally clay or shale occurs in small lenslike masses or pockets in the sandstone. Bownocker[a] claims that in certain Ohio sandstones the clay masses were probably formed by mud from the overlying shales working down into the sand before the latter was consolidated. On account of their softness, water absorption, and easy disintegration, clay masses crumble rapidly and leave a pitted surface. If such masses are large or numerous, they will appreciably weaken the stone.

Clay may also occur disseminated throughout the rock mass as a cementing material in the intergranular spaces. Such argillaceous sandstones absorb water readily and therefore disintegrate rapidly, especially when subjected to frost action. Moreover, the presence of clay weakens the rock perceptibly.

Clay or shale may therefore occur as continuous beds separating beds of sandstone, a form in which it is not a serious impurity if the beds are thin; it may occur in discontinuous bands, lines, or pockets, which cause a pitted and nonuniform surface; or it may occur as a dissemination throughout the entire rock mass, being its most objectionable form.

CARBONACEOUS MATTER.

Thin films of carbonaceous matter resembling coal occur in certain sandstones. They are the result of the deposition of small amounts of organic vegetable matter at the time the sand was deposited, and therefore they follow the bedding planes of the sandstone. Although they are usually thin, their black color makes them conspicuous. If numerous, they tend to weaken the rock. Blocks containing black streaks can be used only for riprap or rough masonry.

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[a] Bownocker, J. A., Op. cit., p. 133.

MICA.

Small shining flakes of white mica are common in sandstone. When scattered uniformly throughout the rock mass they are not injurious, but when segregated in bands and zones they appear as streaks on the rock surface and form planes of weakness.

PETROLEUM COMPOUNDS.

Many sandstone quarries are situated in oil-bearing formations, and there is therefore the liability of petroleum compounds being disseminated throughout the rock mass. Oil compounds are objectionable, mainly because they collect dust and thus cause surface discoloration. If they occur in certain spots only dark patches result. It is claimed by Bownocker[a] that oil not only disfigures but weakens the stone.

WHITE STREAKS AND SPOTS.

White streaks when parallel with the bedding are probably due to variations in the proportion of iron oxides in the original sands. They mar the appearance of the stone, but otherwise may have no ill effects.

White spots are common in buff or brown sandstones. They are usually round and vary in size from one-eighth to three-fourths of an inch. It has been suggested that a small amount of organic matter may first cause a reduction of the iron content adjacent to it and later cause the iron to be dissolved. The finding of organic nuclei in the centers of some of the light spots gives support to this hypothesis. The late C. A. Davis[b] states that brown sandstones adjacent to peat deposits are commonly bleached white when they come in contact with the peat, and that the ash from the peat may contain sufficient iron oxide to constitute a red ocher. It is apparent that the peat has extracted iron oxide from the sandstone. He also states that when the white spots in brown sandstones are treated with an iron salt and heated with a blowpipe, the original brown or reddish color may be reproduced.

QUARRY METHODS THAT CAUSE WASTE.

In addition to the waste occasioned by rock imperfections, the proportion of waste may be further increased by faulty quarrying. Inefficient methods of blasting, channeling, and wedging that tend to increase waste are described in the following paragraphs.

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[a] Bownocker, J. A., Op. cit., p. 126. [b] Personal communication.

WASTE DUE TO BLASTING.

If a proposed use requires that the integrity of the rock be maintained, the greatest care should be exercised in blasting. The separation into smaller pieces of a block already free requires only light charges, especially when the Knox system is employed, and the danger of shattering is correspondingly small. When it becomes necessary to break large masses free from the ledge, occasionally charges of sufficient magnitude are employed to move the entire mass several inches from its original position. This practice involves great danger of shattering, and may therefore result in considerable waste of good stone.

If the mass is tight on two sides, heavy blasting is required. The method of breaking a mass free at two sides simultaneously has already been described on page 37. Destructive fracturing is sure to result from the heavy charges required.

In thin-bedded sandstone quarries blasting often results in uneven breaks, with consequent waste in reducing the blocks to uniformity, especially if the blast holes are spaced far apart.

If the sandstone has a "run," or easy splitting direction perpendicular to the bedding, an uneven surface will result if an attempt is made to force a break in a direction at an oblique angle with the run, as is clearly illustrated in Plate III, *A* (p. 50).

WASTE DUE TO CHANNELING.

Probably the most common mistake in channeling that results in excessive waste is the attempt to force the machine to its greatest capacity in order to attain a high cutting rate in square feet per day. Fast cutting requires heavy blows, which result in the formation of minute cracks running from the walls of the channel cut into the rock mass. Such fractures may destroy rock for a depth of 2 feet on each side of the channel cut. The formation of fractures by this means is what quarrymen call "stunning." Although sandstones are variable in their susceptibility to stunning, practically all of them are liable to suffer more or less damage if the channeling machine is forced to its utmost capacity.

In channeling inclined beds, if the channel cut passes obliquely with respect to the direction of dip, floor breaks parallel with the dip will result in the formation of angular blocks with consequent waste in trimming to regular form, as is illustrated in figure 5 (p. 44).

In channeling wall cuts along an extended quarry face the successive sections of the wall may not always be in line, but may present a zigzag or curving face, as illustrated in Plate VI, *B*. With continued quarrying of such a ledge, it is evident that in order to

keep the lateral cuts perpendicular to the quarry face with each successive section there must be a change in the direction of the lateral cuts, so that triangular blocks will be formed. Such a condition must therefore result in the production of an undue proportion of angular fragments which must be consigned to the waste heap.

WASTE DUE TO WEDGING.

Bed seams are not always continuous, but may become obscure and finally close up entirely. When masses of rock are lifted by driving wedges in such noncontinuous seams a fracture may be formed in that part of the bed where the seam is closed, and the fracture thus formed may run in a diagonal direction, or be otherwise so irregular that waste will result.

Similarly, a very uneven fracture may be formed when an attempt is made to lift a wide block in cross-grained stone. It is well known to quarrymen that a wide mass of split rock may be raised with little risk of a crooked break, but with cross-grained rock the fracture may run on the inclined grain and give a most unsatisfactory fracture.

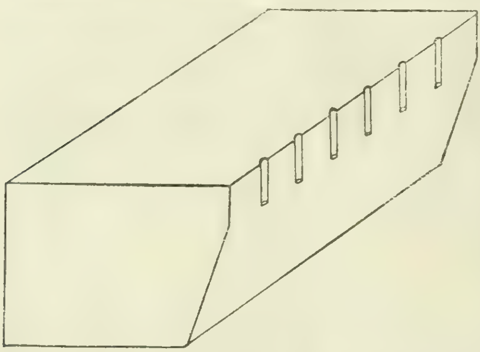

FIGURE 15.—Inclined break that may occur in certain sandstone blocks where shallow wedge holes are employed.

Wedging to form vertical breaks may also result in the formation of irregular surfaces. The irregularities may be due to spacing the wedge holes too far apart, especially if the run is poor, or to an attempt to break the rock in a direction oblique to the run. Furthermore, they may result from the wedge holes being too shallow. There is in certain sandstones a strong tendency for the rock to break in a slanting direction from the bottoms of shallow wedge holes, as is illustrated in figure 15.

MISCELLANEOUS CAUSES OF WASTE.

Waste may ensue from quarrying rock so late in the autumn that it has not sufficient time to season before freezing. In deposits in which frost is liable to damage the ledge good rock may also be destroyed if the exposed ledge is not protected during the winter months.

In certain sandstone deposits which dip toward an excavation at a steep angle and have clay seams interbedded, an overloading with

débris may cause movement of a bed on the clay seams, resulting in the formation of irregular destructive fractures.

WASTE ELIMINATION.

IMPORTANCE OF WASTE ELIMINATION.

In view of the limited number of uses for which waste sandstone may be employed, the elimination of waste is a matter of supreme importance to the quarryman. To the expense of quarrying material for which little or no use may be found is to be added the difficulty of its disposal and the inconvenience occasioned by its presence where an unobstructed field of operation is to be desired. Every precaution should therefore be taken to reduce to a minimum the proportion of waste rock quarried. The fact that in some sandstone quarries the proportion of waste is 75 per cent of the total rock quarried is evidence of the necessity for a careful study of the problem of waste elimination. The conduct of quarry affairs tending toward a reduction in the proportion of waste is discussed in the following paragraphs.

NEED OF CAREFUL PROSPECTING.

The prospector should not allow himself to be influenced by undue optimism with regard to the probable proportion of good stock in a sandstone ledge. It must be realized that it costs almost, if not quite, as much to remove waste blocks from the quarry as to remove sound and uniform stock. The condition of jointing and the presence of mud pockets, "hard heads," streaks, staining materials, or other imperfections must be studied with a view to determining the proportion of waste that they are likely to involve. A field of active operation should naturally be chosen in the ledge or part of the ledge that gives promise of the smallest proportion of waste.

QUARRYING IN ACCORDANCE WITH JOINT SYSTEMS.

Joints in sandstone are usually more continuous and more widely spaced and their systems less complex than in marble deposits, and as a consequence quarrying in conformity with them is usually simple. The obvious method of reducing to a minimum the waste resulting from joints is to make channel cuts or breaks parallel with or at right angles to them and to space the cuts or fractures in such a manner as to make them as far as possible coincident with the joints. Figure 16 illustrates the saving of material which may be thus effected. The joint systems are identical in *A* and *B* of this figure. At *A* the channel cuts cross the joints obliquely and are equally spaced; at *B* the cuts are made parallel with the joints and

are spaced in such a manner as to coincide as far as possible with them. At *A* all the blocks are intersected by joints, whereas at *B* nearly all are sound, showing clearly that waste may be largely elim-

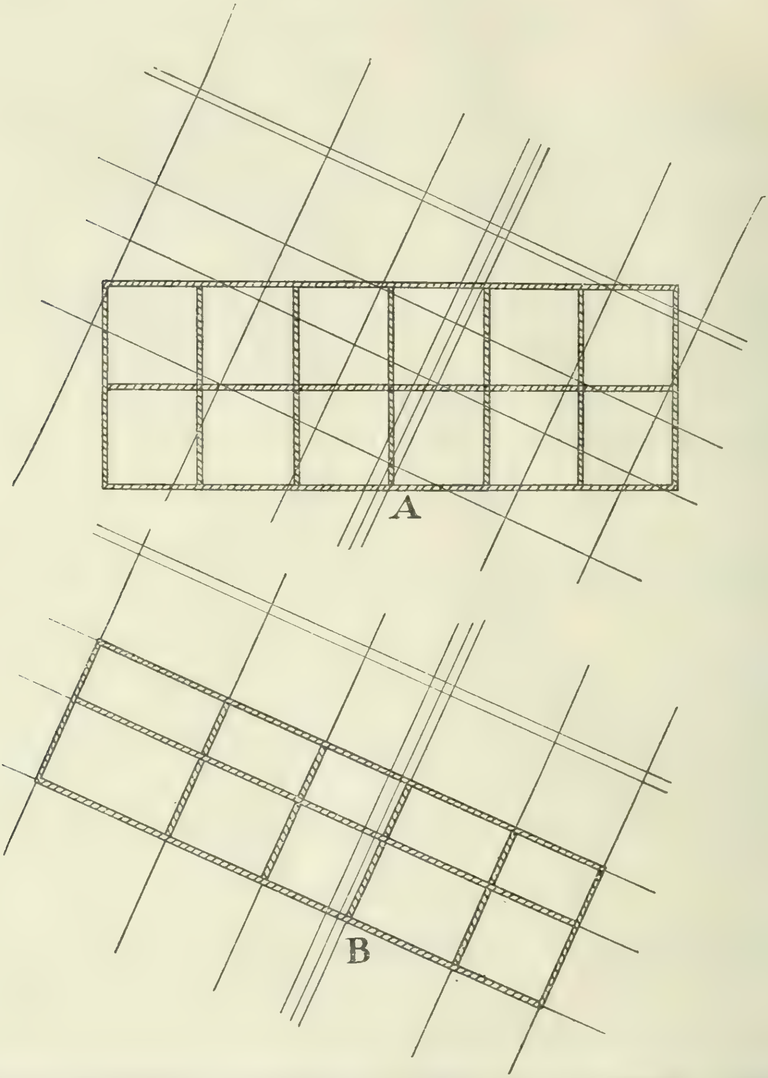

FIGURE 16.—The economy of channeling in accordance with joint systems. *A*, plan of channeling without reference to direction or spacing of the joints, involving great waste of sandstone; *B*, plan of channeling in which channel cuts are made parallel with, and, as far as possible, coincident with, joints, avoiding waste of blocks.

inated by carefully examining joints to discover their systems and by quarrying in such a manner as to make the best of them.

QUARRYING IN ACCORDANCE WITH BEDDING.

In quarries having inclined beds it is advisable wherever possible to channel parallel to dip and strike, or otherwise splitting on the bed will result in the production of blocks having oblique angles, as is illustrated in figure 5 (p. 44). If the original layout of the quarry is at fault, it may be advisable to change the direction of quarry walls to conform with dip and strike. In cross-grained beds there may be a tendency to split at an angle different from the angle of dip of the larger bedding planes, and under such conditions satisfactory quarrying may be difficult.

AVOIDANCE OF "STUNNING."

Sandstones vary in their susceptibility to "stunning," but all of them are more or less damaged when the channeling machine steel strikes heavy blows. Fortunately the stroke of most channeling machines can be adjusted in such a manner that they will strike

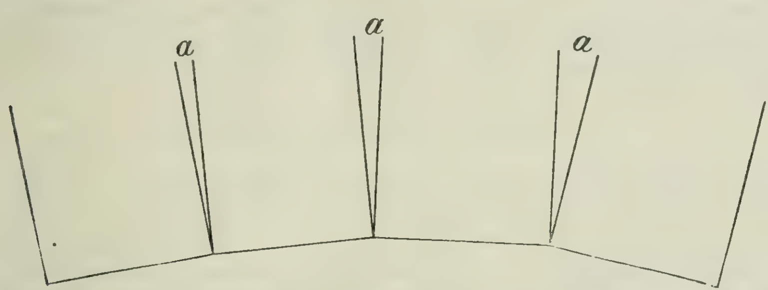

FIGURE 17.—A lack of parallelism in successive sections of a quarry face; *a*, triangular rock masses which must be quarried.

light blows. Channeling machines should, therefore, be carefully adjusted to preserve the rock from the effects of stunning, even at the sacrifice of speed. The destruction of 6 inches to 2 feet of rock adjacent to channel cuts is a loss that even a great increase in the rate of channeling can not justify.

MAINTAINING STRAIGHT QUARRY WALLS.

As illustrated at *a*, figure 17, triangular masses, which do not work to advantage, are produced when various sections of an extended quarry face are not parallel. This is also illustrated in Plate VI, *B* (p. 74). The shape of the area stripped, or some other immediate cause may influence the quarryman to make a curved or irregular face. However, it is much better to make right-angled steps in the face and thus maintain parallelism. Stripping should be planned in such a way as to leave a surface suitable for working the ledge as a continuous straight wall, but if this is not practicable the face should be offset by a series of right-angled steps.

PRECAUTIONS TO BE TAKEN IN BLASTING.

Where sandstone is quarried for building or other purposes for which sound blocks are demanded, blasting should be avoided or conducted with extreme care. Sufficient explosive should be used to make a fracture only, and not enough to move a great mass of rock bodily. The Knox system gives best results, as reaming promotes straight splitting, and the air space presents a comparatively wide surface upon which the force of the explosion is exerted. Blasting should be employed only to separate the rock mass along a single plane. The breaking of two faces simultaneously requires heavy charges and shatters the rock. In subdividing large masses the charge should, wherever possible, be balanced; that is, an equal mass of rock should lie on either side of the plane of separation. If not properly balanced, the break is inclined to run toward the lighter side, with consequent angularity of the block produced. If the rock has a decided run or easy-splitting direction, no attempt should be made to force breaks in directions inclined obliquely to the run, as more explosive is required, and the surfaces obtained are more irregular than when the break parallels the run.

PRECAUTIONS TO BE OBSERVED IN WEDGING.

When beds with imperfect bed seams that close up entirely in places are lifted, wedges are sometimes driven into the open part of the seam only, and an irregular break may thus be formed where the bed is tight. If a continuous grip is cut and numerous wedges are driven, a better break will probably be produced. In lifting a wide mass of cross-grained rock, the fracture may follow the cross grain and pass in an oblique direction, or may otherwise give an undesirable fracture. In cross-grained rock it is wise to lift only narrow masses. In northern Ohio masses of split rock 12 feet wide are raised successfully, whereas in cross-grained rock no attempt is made to lift masses more than 6 feet wide.

If there is a tendency for a break formed by wedging in shallow drill holes to slant off at an angle from the bottoms of the holes, as illustrated in figure 15 (p. 84), it may be wise to drill deep wedge holes or to substitute blasting for wedging.

ADVANTAGE OF GOOD MILLWORK.

Blocks containing many small clay pockets, streaks, or spots may be sawed in such a manner that these imperfections will not appear on the faces of the blocks. Thus a block which, if cut at random, would probably be useful for only rough building purposes, may by careful handling be so cut as to permit its use for purposes

requiring the highest grades of stone. There is an advantage in operating a mill in connection with a quarry, for the quarryman understands his rock, and is therefore enabled to cut it to much better advantage than a millman who is not acquainted with its peculiarities. Moreover, the sawing of a block may reveal the presence of imperfections otherwise unseen, and such as to be sufficient to condemn the rock. When such imperfections are discovered while the rock is still in the vicinity of the quarry, the cost of transportation of waste material is saved.

UNIFORM GRADING.

A proper grading and classification of material enables the quarryman to dispose of his stock to the best advantage. Careful quarrying is necessary for proper grading. If blocks consisting of mixed high-grade and low-grade stone are quarried, they must be classed as low grade, and the higher price that might otherwise be realized for the high-grade parts is thereby lost. Separation of rock masses both vertically and horizontally should therefore be conducted with a view to obtaining uniformity of grade in each individual block. Careful millwork is also necessary for the uniform grading of mill products.

WASTE UTILIZATION.

MARKETING OF UNAVOIDABLE WASTE.

When quarrying is conducted in the most economical manner possible there is still a varying percentage of quarried rock that must be classed as waste. In order that the expense of handling this rock may not be entirely lost, markets are sought where it may be sold. even though the sum realized from its sale may be only a fraction of the cost of excavation. Unfortunately the opportunities for using sandstone waste are not as numerous as those for using waste limestone and marble. The latter rocks may be utilized extensively for agricultural purposes, lime, cement, and road material, for all of which uses sandstones are not adapted. The chief uses of waste sandstone are discussed below.

USE OF ODD-SIZED PIECES FOR RIPRAP.

Heavy, irregular blocks of sandstone may be used for shore protection along rivers, for spillways at dams, or for the construction of harbor breakwaters. The situation of quarries with respect to navigable waters is of considerable importance, as freight rates prohibit long haulage by rail. The demand for riprap is liable to fluctuate greatly, as rock of this type is used for work of a noncontinuous nature. Railway construction requires considerable riprap for filling.

For certain uses riprap of a smaller size than many of the original waste blocks is required. Mud-capping ("adobe") or block-hole blasting is commonly employed to break the larger masses. A ball breaker is used for this purpose by one Kentucky company. A heavy iron ball is hoisted with a derrick, is centered over a block, and tripped. The impact of the ball breaks the block into fragments. The cost of power involved is much less than the cost of drilling or of explosives employed for the ordinary method, and the process is said to be more effective. In this connection reference may also be made to the use of a similar ball breaker in a marble quarry.[a]

ASHLAR, RUBBLE, AND CELLAR-WALL STONES.

Fragments small enough to be handled by one or two men and having one good face may be sold for rubble if there is a sufficient demand for stone of this type. A rock of lower grade than rubble, known as cellar-wall stone, consisting of irregular small fragments,

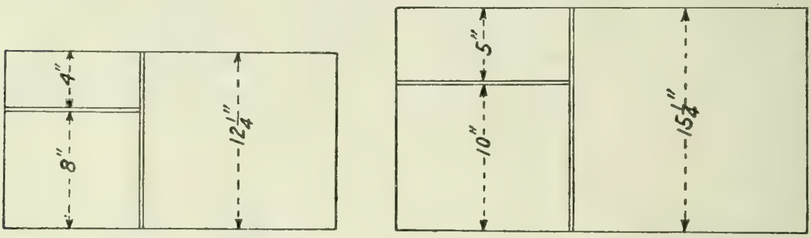

FIGURE 18.—Six standard sizes of ashlar fitted together to make walls.

is used to some extent for foundations of buildings, although concrete is used widely as a substitute of late years.

Stone may be economized by a judicious utilization of waste fragments from the higher grades to make blocks of lower grade. Thus the larger waste fragments from dimension stone may be used for ashlar, and the smaller pieces may possibly be crushed for use as a road base or for sand-lime brick. Similarly the fragments resulting from the manufacture of ashlar may be used for rubble or cellar-wall stone, and the smaller pieces for purposes similar to those described above.

Rock of different sizes may be used to advantage in making the various sizes of ashlar. One sandstone company finds it very advantageous to make ashlar of six standard thicknesses, as follows: 4-inch, 8-inch, 12¼-inch, 5-inch, 10-inch, and 15¼-inch. These sizes fit together in making broken ashlar walls in the manner shown in figure 18. In this way many fragments that otherwise would be entirely

[a] Bowles, Oliver, The technology of marble quarrying: Bull. 106, Bureau of Mines, 1916, p. 120.

wasted or used as rubble or cellar-wall stone are utilized for the more valuable ashlar.

CONCRETE AGGREGATE.

Waste sandstone may be crushed for concrete. It is claimed that the rough surface of the sandstone fragments and their porosity permit the cement to permeate the rock fragments and adhere firmly to them, thus producing strong cement. If crushed porous sandstone is used dry its capacity for water absorption will tend to dry the concrete mixture too rapidly. This disadvantage may be overcome by soaking the rock fragments in water before adding them to the mixture. If sandstones are friable a large proportion—possibly one-third to one-quarter of the rock mass—may be pulverized to sand in the process of crushing, and for the best service in concrete this sand should be screened out. If the sand can not be sold considerable loss is involved.

SAND-LIME BRICK.

At least one sandstone company crushes all the suitable material that can not be otherwise disposed of, and uses it for manufacturing sand-lime brick. Although the outlay of considerable capital is required to establish an efficient brick plant, the market for the product is said to be active, and the returns are on the whole satisfactory. If the quarryman has abundant waste material suitable for such a purpose—material that must otherwise be handled with no compensating return and may be much in the way of quarry operations—the erection of a sand-lime brick plant may be profitable, provided sufficient capital is available and provided the market for the product is adequate.

ROAD MATERIAL.

As a rule, sandstone is not a satisfactory material for road surfaces, although some argillaceous sandstones contain sufficient binding material to render them satisfactory. A quartzite from southwestern Minnesota has given good service, however, under heavy traffic. A test by the United States Department of Agriculture shows it to have the following composition:

Composition of quartzite from southwestern Minnesota.

	Per cent.
Quartz (silica)	96.3
Orthoclase (silicate of alumina and potash)	1.4
Zircon (silicate of zirconium)	.1
Hematite (oxide of iron)	2.2

Although its cementing value is low, this property can be greatly increased by rolling it wet, with plenty of water. Roads finished wet will probably give the best service under heavy traffic. It is probable that the more friable types of sandstone give much poorer service, as they are easily pulverized into sand.

For road bases, however, sandstone may give excellent results, as it provides good drainage and cushion. Much of the Ohio sandstone has given good service as road-base material when covered with tar or finished with limestone.

UTILIZATION OF SAND.

Sand obtained from sandstone crushing or grinding, or by screening crushed stone, may be used for certain purposes, as for mortar or furnace floors. Sand for glass or pottery manufacture must consist of nearly pure silica, and few quarries operated for the production of block stone have rock of sufficient purity for this purpose, although exceptions may occur.

MISCELLANEOUS USES.

Small fragments that result from the manufacture of large grindstones may be used for making small grindstones or whetstones, or, if of sufficient uniformity and fineness of grain, for razor hones. Highly refractory sandstones may be used for open-hearth furnace lining.

WASTE DISPOSAL.

From the foregoing discussion it is evident that the first step in the solution of the problem of waste is to quarry in such a manner as to produce as little waste as possible, and that the second step is to utilize in every possible way the waste material that must of necessity be quarried, even when the most economical methods are employed. A third and last step involves the cheapest and most convenient means of disposing of the residue of waste that can be neither eliminated nor utilized.

DISPOSAL IN ABANDONED PITS.

A common method of disposal of both mill and quarry waste is to dump it into abandoned pits or to return it to worked-out parts of excavations. Dump cars, tripped automatically or by an operator, are commonly used. For sentimental reasons some quarry owners preserve old excavations as evidence of the extent of past operations. The fact that such excavations may be utilized to advantage for waste disposal, and thus save money for the company, is becoming apparent in many quarters, and is gradually overcoming the mere

sentimental considerations. Such utilization of pits should never be made, however, before sufficient investigation has been conducted to convince the operator that the excavations should never be reopened.

Attention may be directed to equipment introduced by a northern Ohio quarryman for conveying waste to the center of large excavations, where work is being conducted at the same time at various points along its walls. Heavy sheet-metal spouts in sections about 20 feet long are attached to two parallel steel cables attached at the upper edge of the excavation, and slanting downward to points beyond where waste is to be dumped. The contents of waste boxes are dumped into these slides, and the material is thus conveyed to points beyond the reach of active quarry operations. The point at which the waste falls may be varied by changing the position of cable attachment, or by adding or removing sections of the spout or slide. This method is much more economical than loading waste in railway cars and removing it to a favorable dumping ground at some distance from the quarry.

DISPOSAL IN RAVINES OR OTHER LOW AREAS.

Where pits are not available, waste may be transported by railway or dump cars to ravines or other low areas. Disposal by this method may be slow and the cost may be excessive if the place of disposal is not convenient or if the means of loading and unloading are not efficient. An overhead cableway hoist is employed by one company. Its elevation above the ground level affords a distinct advantage over the dump-car method in that it allows an accumulation of material to a much greater height without interference with transportation or any increase in the difficulty of unloading. An overhead tramway by which the waste is conducted with stripping over roads and railroads to an available dumping ground has been noted. It is an expensive method involving high first cost and high cost of maintenance.

BLUESTONE.

PHYSICAL PROPERTIES OF BLUESTONE.

BLUESTONE AS A COMMERCIAL ROCK TYPE.

Bluestone is a commercial name for a variety of sandstone having properties sufficiently characteristic and distinctive to justify its recognition as a separate rock type. The term was first applied to certain blue sandstones quarried in Ulster County, New York. With the development of the industry it was found that stone of similar character was abundant in many parts of New York and Pennsylvania. The stones in various localities differ considerably in com-

position, size of grain, and color, but are all dense and compact, hard, usually dark in color, and in the upper beds at least can be split into thin and uniform slabs. The term "bluestone" is therefore applied to all varieties, irrespective of color. Blue, gray, red, pink, and greenish colors have been observed.

COMPOSITION.

As the result of a microscopic study of bluestone from Ulster County, N. Y., made by Berkey,[a] he states that the rock consists of feldspars, quartz, sericite, chlorite, calcite, clay, and a little pyrite and organic matter. Hornblende and biotite were probably present in the rock originally, but have entirely altered to the more stable sericite and chlorite. The grains are angular and are held together with a strong siliceous cement. It is therefore classified as an indurated arkose sandstone. Although certain variations in composition and texture may occur in bluestone from various localities, in general they are all of this type.

STRUCTURAL FEATURES.

JOINTS.

Joints are usually in two vertical systems nearly at right angles to each other and 5 to 60 or 70 feet apart. In general the systems are north-south and east-west. The former are termed "heads" and the latter "sides." Usually they are straight, though sometimes curved and irregular. Merrill[b] states that in Delaware and Broome Counties the east-and-west joints are liable to be very irregular. Occasionally two irregular joints are so close together that the mass of rock between them produces blocks of variable size and shape, much of the rock being waste material. A quarryman's local term for such a mass is "a cat-faced block."

BEDS AND REEDS.

Most bluestones are in a horizontal or nearly horizontal attitude. Open bedding planes are a few inches to several feet apart, or in the massive rock may be at intervals of 25 to 35 feet. Interbedded shales are common, such rock being termed "pencil" by quarrymen.

The most characteristic structure of bluestone is its weak cohesion in certain well-defined planes, resulting in a strong tendency to split in thin sheets parallel with the bedding. Usually in the upper beds the partings are developed to such an extent that the rock splits with

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[a] Berkey, C. P., Quality of bluestone in the vicinity of Ashoken Dam: School of Mines Quart., vol. 29, 1907–08, pp. 154–156.

[b] Merrill, F. J. H., Quarrying of bluestone and other sandstones in the Upper Devonian of New York State: New York State Museum Bull. 61, 1903, p. 7.

great ease into thin slabs of large size. At greater depths the partings are less pronounced, though in most beds the rock may be split easily along certain streaks termed "reeds." The tendency to split in this manner is therefore occasioned by some change or pause in the process of sand deposition, resulting in a lack of cohesion between successive layers, and this lack of cohesion is further emphasized by weathering. Berkey,[a] after a microscopic examination, states that "the reed is strictly a rock structure and the perfection of the capacity to split along these planes depends wholly upon the abundance, arrangement, and size of the elongate and semifibrous grains and the presence of a more than usual amount of original fine or flaky material. Almost universally the reed streaks are darker in color and finer in grain than the average of the rest of the rock." This property of bluestone has made it a valuable rock for the production of flagging.

In some deposits or in certain parts of deposits this tendency is lacking. Cross-bedding may be present or the stone may be massive, a "liver rock." In some quarries such beds are avoided because flagging can not be made from them. For structural purposes, however, they are the strongest and most durable, and therefore the most valuable.

THE "RUN" OF THE ROCK.

There is usually in bluestone one vertical plane in which splitting is comparatively easy. This is known as the "run" of the rock or the "free way," and the vertical plane at right angles to it is termed the "hard way." In some quarries where this feature was investigated the run is east and west, and the hard way north and south. Merrill[b] states that in Ulster County, N. Y., the run is north and south, whereas in Delaware and Broome Counties it is east and west.

STRENGTH.

Bluestone of good quality is very strong. The mass of rock without reeds is stronger than the reedy rock, and therefore better adapted than the latter for structural purposes. Berkey[c] states that the great strength of the rock is due to the fact that the alteration of the ferromagnesium and aluminous minerals, has set free considerable secondary quartz which has attached itself to the original quartz grains, making them more angular, and developing an interlocking texture, and that the secondary fibrous minerals have promoted further interlocking of the grains. Tests recorded by Merrill[d] indicate that blue-

[a] Berkey, C. P., Op. cit., p. 156.
[b] Merrill, F. J. H., Op. cit., pp. 10–11.
[c] Berkey, C. P., Op. cit., p. 157.
[d] Merrill, F. J. H., Op. cit., p. 188.

stone quarried near Oxford, N. Y., has a crushing strength of approximately 13,000 pounds per square inch across the bed and 12,000 pounds parallel with the bed.

DURABILITY.

Bluestone is probably the most durable of any quarried stone except quartzite. The coarse-grained varieties are somewhat more resistant to weathering than those of finer grain. The presence of clay in the bluestone renders it less durable. When natural outcrops of bluestone along steep hillsides are being examined, the more durable beds can be easily recognized by their steep, almost clifflike contour, whereas the softer and more easily weathered beds outcrop as more gradual slopes. Thus if the ledge consists of alternating hard and soft beds, the face of the hill will in like manner present alternating clifflike terraces and gradual slopes.

USES OF BLUESTONE.

Bluestone is used very widely for sidewalks, and for other purposes where flagging is required. It is well suited for this purpose, as it retains its rough surface, and resists wear, and owing to its low ratio of absorption, ice and rain remain on it only a short time.

Bluestone with reeds more widely spaced is used for curbing, steps, sills, caps, water tables, and coping. Heavy mill blocks are sawed into forms suitable for the various purposes mentioned above, or into building blocks. The rock is used to some extent for floor tile. Various colors may be combined to make attractive floor patterns or borders. The more massive varieties of bluestone are suitable for heavy masonry. Crushed bluestone is used to some extent for concrete aggregate.

COMMERCIAL TYPES.

Quarried bluestone is marketed in three distinct forms: Flagging, "edge stone," and "rock" or mill blocks.

Flagging is produced from the easy-splitting beds. Bluestone from many deposits splits with remarkable ease into thin and uniform sheets. Commonly sheets 10 by 12 feet are split out in slabs 2 inches thick.

What is termed "edge stone" splits out in thicker beds and is dressed for curbing, sills, caps, and coping or other similar uses.

"Rock" or mill blocks are taken from the more massive beds that are not reedy, and are therefore well suited for structural purposes. Mill blocks are more valuable per cubic foot than the other forms quarried.

GENERAL QUARRY METHOD.

Bluestone quarrying differs from most other types in that there are few large quarries and a very large number of small ones. Numerous small openings quarried by one to eight men are operated during the summer months, some being worked at brief intervals only in connection with farming or other occupations. The product is hauled out by teams and sold to rock dealers. Although the quarries are mostly small they are numerous, the total production for the States of New York and Pennsylvania amounting to over $1,000,000 a year.

STRIPPING.

The overburden, or what quarrymen call "top," may consist of soil, shale, or waste bluestone or combinations of these substances. The thickness of stripping that can be profitably removed depends on the nature of the material, place available for its disposal, and the thickness and quality of the underlying available stone. It may be stated approximately that quarrying can scarcely be made to pay if the depth of "top" is more than three times as great as the depth of serviceable stone.

As in the case of other sandstone quarries, stripping is usually conducted in the winter. The soil can be blasted and handled more expeditiously when frozen than otherwise. Removal of soil is accomplished in small quarries by shovel and wheelbarrow, by dump cart or by small cars on tracks. Masses of waste rock are handled by the quarry derrick, if such is present. In the process of blasting overburden some quarrymen first squib out the holes with dynamite and then complete the operation with heavy charges of powder.

A unique method of blasting overburden is employed at certain quarries situated at high levels along the Lehigh River bluffs. The "top" is 35 to 50 feet thick and consists mainly of shattered shale and bluestone. A well is excavated some distance back from the face and to the full depth of the stripping. In this well heavy charges of black blasting powder are placed, $1\frac{1}{2}$ to 2 tons being commonly employed. The force of the explosion hurls great masses of the débris over the cliff face, thus disposing of much of the material without further handling. Other masses are so completely broken up that removal is easy.

In some instances stripped material has been insufficiently removed or dumped in places where it is greatly in the way of future operations. A second handling of stripping greatly increases the cost of quarrying and operators should exercise sufficient foresight in the disposal of all waste material so that rehandling will be unnecessary.

QUARRY EQUIPMENT.

In the many small quarries the equipment is limited to the necessary tools and appliances, such as crowbars, shovels, hammers, points, drills, wedges, picks, plugs, and feathers. In numerous quarries no derricks are provided, the rock being handled by crowbars. Handpower or horsepower derricks are common and in a few cases steam or gasoline engines are employed to operate derricks. Some derricks are provided with gears giving two speeds, a rapid speed for light loads and a slow speed for heavy loads. Some of the larger quarries have compressed-air plants for operating drills. For drainage purposes steam or gasoline pumps or pulsometers are operated in a few places. In others siphons are employed and in many quarries the conditions favor automatic drainage. A blacksmith shop for sharpening and shaping tools is a necessity for every quarry.

QUARRY METHODS.

METHOD OF WORKING OUT LARGER MASSES.

Vertical seams in bluestone commonly occur in two systems at right angles to each other and spaced 10 to 30 feet apart. The quarryman endeavors to work to these seams whenever possible. Where seams are far apart, it may be necessary to make an artificial cross break. This process is termed "snubbing." It is accomplished usually by drilling holes about 6 feet apart and blasting by the "Knox system." The masses thus separated are commonly 15 by 20 feet or 20 feet square and 1 to 3 or 4 feet thick, depending upon the spacing of the open bed seams. Another method less commonly used is to drill a row of close holes about 1 inch or 1½ inches apart, and to broach out the intervening masses, thus making a continuous cut.

SUBDIVISION OF LARGER MASSES.

CROSS BREAKS BY DRILLING AND WEDGING.

Hand drills are employed in small quarries, and in the larger ones steam or compressed air is used. Compressed air is the most satisfactory, especially since the introduction of small air-operated drills suitable for hand manipulation. The hollow steel through which the exhaust air blows out the cuttings is a useful device.

For drilling wedge holes in reedy rock an improved method is to use a "starter" and a "follower." The starter drill is commonly 1⅛ inches in diameter, and is used to drill only the upper 1½ inches of the holes. Then the follower, which is a drill of ⅞-inch diameter, is used to finish the holes. In the process of wedging in such holes the pressure of the plugs and feathers comes at some distance below the

surface of the rock, whereas if the holes are of the same size throughout their full depth the pressure is inclined to be excessive near the surface, and causes the rock adjacent to them to shell off. In massive rock that does not split easily on the bed such a method may not be necessary. A row of pick holes along the line of wedge holes helps to make a straight break. A method commonly followed in breaking thin beds may be of interest. For a bed 1 foot thick the drill holes are usually $\frac{5}{8}$ to $\frac{3}{4}$ inch in diameter, about 6 inches deep and 1 foot apart. Three pick holes about 1 inch deep are cut out in each of the 1-foot intervals to promote straight splitting. Plugs and feathers are placed in the drill holes and driven successively with a light hammer, care being taken to produce a uniform strain all along the line. If the run is pronounced and splitting is parallel with the run, the holes may be spaced considerably farther apart than where the break is made parallel with the hard way.

It is thought by some quarrymen that it would be wise to use smaller drills than those referred to above. When large drills are used, the deep semicircular grooves on the broken surfaces make considerable trimming necessary in order to bring the edges down to an even plane. When small drills are used much less trimming is required.

CROSS BREAKS BY BLASTING.

When large masses are separated, it is sometimes found advantageous to make further subdivision by drilling and blasting, and effective blasting has been accomplished in some quarters. The use of a single reamed hole for masses up to 18 feet square and 3 to 4 feet thick has in some rock given better results than several holes placed in line.

An interesting experiment was tried in a New York quarry to ascertain whether it was possible to break a block 20 feet square and 3 feet thick in two directions at right angles, and thus quarter it, by discharging a single shot in a centrally placed hole reamed in two directions at right angles. The result was that separation took place along one of the desired directions only, a direction in line with the run of the rock. If a block is considerably narrower in a direction at right angles to the run than it is in a direction parallel to the run, simultaneous breaks in both directions may possibly be made with a single shot.

It is customary in many quarries to blast the rock parallel with the run and to wedge it in a direction at right angles to the run. Breaking is comparatively easy in a direction parallel with the run, and even though the holes may be far apart a straight break will probably result. Blast holes are usually spaced 5 or 6 feet apart. With such wide spacing a straight break is more likely to occur

parallel with the run than parallel with the hard way. On the other hand, wedge holes are made closer together, and wedging usually gives a straight break, even when made across the run.

However, in some quarries in which the beds are massive and 3 to 4 feet thick, wedging in shallow drill holes may result in the break running off at a slant from the bottoms of the holes, as shown in figure 15 (p. 84). On the other hand, holes for blasting are nearly the full depth of the block, and thus blasting would prevent the break running in this manner. Therefore, in rock having these peculiarities the processes are usually reversed, blasting being employed parallel with the hard way, and wedging parallel with the run.

BED SPLITTING.

The ease of bed splitting is variable. In rock in which the reeds are pronounced, splitting is easily accomplished with wedges, and a smooth and even surface is usually produced. Such rock is employed for flagging.

In the more massive beds splitting is more difficult. It is usually accomplished by driving points or wedges in shallow holes cut out with a point and hammer. A typical method of splitting a 2-inch slab from a block 5 feet long, 2 feet 6 inches wide, and about 7 inches thick is as follows:

Rows of holes 3 inches apart and about half an inch deep are made up each end and along one edge of the block with a point and hammer. A fracture is started by driving points into the holes successively first at one end of the block and then at the other end. When a fracture is formed for some distance from each end thin wedges are driven into it at both ends and on the edge. The block is then turned down and started on the opposite edge and the fracture is completed by wedging. When the process is thus carefully conducted it gives a uniform fracture.

A method of splitting out thick masses from which curbing is to be made is as follows:

A mass of sufficient thickness to make about four curbstones is lifted from the quarry floor. It is marked with a point on the four edges at intervals that give the desired thickness for curbstones and is then split with a "bull point"—a large point driven with a sledge.

TRIMMING.

There is usually need of edge trimming, especially where curbstones, steps, coping, and the like are made. When such trimming is done in the quarries hand tools and hammers are usually employed. Where curved corner curbstones are made a great deal of trimming must be done. With careful handling two corner curbs may be

broken from a single block by making a curved break. As noted in a previous paragraph, the necessity for excessive edge trimming may be lessened by using drills of small diameter.

The amount of trimming required is influenced also by the presence of cross bedding, which may result in oblique bed splitting. If a slab for curbstone is thicker at one edge than the other, it is "pitched off" with a hand tool and hammer, a process that is wasteful of rock and requires much time and labor.

TRANSPORTATION.

The operators of the many small bluestone quarries sell their product to stone dealers. The latter have yards termed "docks," situated on navigable water or railway lines, the rock being unloaded when hauled from quarries and shipped by rail or water to its destination. The docks are almost invariably equipped with derricks. The dealers may also operate quarries, or they may simply buy and handle rock quarried by others. Transportation is almost invariably by wagons, as very few quarries have railway sidings. Teams of two, three, or four horses are employed, and the loads hauled may attain a maximum weight of 8 or 10 tons. Loading is done by derrick wherever such equipment is present. Where no derricks are employed gangs from the different quarries help each other in loading if the quarries are situated at convenient distances.

As many of the quarries are at high levels, roads leading down from them to the main roads are commonly precipitous and in poor condition. The chaining of wagon wheels to retard the descent causes the roadways to be cut and makes their repair difficult.

The cost of transportation is borne by the quarryman and varies from 8 to 50 per cent of the value of the stone, depending on haulage distance and the condition of roads.

From some quarries situated along the Lehigh River the rock is hauled over bad roads and is then ferried across the river to the docks, situated near the railway line. In the author's opinion some of the quarries are admirably situated for overhead cableway equipment, so arranged that the rock could be transported directly from the quarries across the river to the docks. It would be wise for operators of quarries situated on bluffs facing the river to obtain estimates on such equipment.

WASTE.

Joints in bluestone usually appear in two parallel sets at right angles to each other, but occasionally they may intersect at oblique angles, with the consequent production of angular blocks. More frequently they are curved or irregular, a condition that not only

leads to the production of irregular masses, but may cause binding of masses in such a way as to make removal difficult. Where joints are closely spaced, especially if they are irregular in form, much waste may result.

Cross bedding may result in crooked bed splitting, producing uneven surface or blocks of uneven thickness, involving waste of material in reducing the blocks to desired uniformity.

Peculiarities in the splitting qualities of the rock may result in waste. A fracture on one reed may jump across to another, producing a slab thicker on one edge than on the other. A proper understanding of these peculiarities and requisite care in meeting them tend to eliminate waste.

The effect of frost on quarried stone not properly seasoned may be destructive, especially as regards rock with reeds, the effect of frost being to open the reeds. If blocks are sufficiently seasoned so that the quarry water has dried out, the frost has no effect. The time required for seasoning depends on the size of the blocks, those only a few inches thick requiring much less time than those several feet thick. As a consequence of this danger rock is not quarried in the late fall or winter.

The open, unquarried ledge may also suffer frost damage. The freezing of water in the reeds opens them, and a bed that in the autumn appears to be sound may in the spring be found to consist of a number of thin slabs. Such partings may be developed for a distance of several feet from the face. The vertical face of a ledge is in less danger of damage from frost than beds that are partly worked out on the quarry floor. A covering of stripping or waste or flooding with water protects the rock from such dangers.

QUARRYING GANISTER.

USES OF GANISTER.

The term "ganister" is here applied to sandstones or quartzites used in the manufacture of refractories. The fusion point of pure silica is 3,300 to 3,400° C., which is a little higher than that of the best fire clays, and consequently silica is a refractory of superior quality. Most of the ganister quarried is ground, mixed with about 2 per cent of lime for a binder, molded, and burned into silica brick, which are used extensively for lining by-product coke ovens, and other ovens in which high temperatures are required. Ground ganister mixed with fire clay is also used for lining converters.

PHYSICAL PROPERTIES OF GANISTER.

The adaptability of sandstone or quartzite for the manufacture of silica brick depends mainly on its purity. The value of the silica brick depends on its fire-resisting properties. the effect of impurities

being to lower the fusion point. Clay is the chief impurity, and is especially undesirable because it greatly lowers the fusion point. Good ganister, therefore, must be free from clay seams, pockets, or lenses. Interbedded clays or shales do not present as great difficulties as the lenses or pockets, because the shale beds can be easily separated from the pure ganister in the process of quarrying.

Iron oxide is another common impurity in ganister. The amount of iron present may be judged approximately by the color of the stone. Red, yellow, or buff colors indicate that iron is present, the iron-free varieties being nearly white. A small iron content is permissible. The Baraboo quartzite of Wisconsin, with upward of 1 per cent of iron oxide, is used for ganister.

The requisite purity of the rock may be judged from the fact that good silica brick has a silica content of 94 per cent or more, the remainder being chiefly lime, which is used as a binder. An analysis given by Seaver [a] of a typical ganister sample from Pennsylvania shows the following composition:

Analysis of typical ganister from Pennsylvania.

	Per cent.
Silica (SiO_2)	97.80
Alumina (Al_2O_3)	.90
Ferric oxide (Fe_2O_3)	.85
Lime (CaO)	.10
Magnesia (MgO)	.15
Alkalies	.40

The shape of the grains and the condition of cementation are also important properties. Incoherent sandstones made up of well-rounded grains when ground give a sand consisting of spherical grains. Quartzites, on the other hand, are so firmly cemented that their original granular nature is lost, and they crush to irregular, angular fragments and splinters. As pointed out by Seaver,[b] the rounded grains do not give as strong a brick as the angular or splintery fragments. Sandstones of the arkose type, which consist of somewhat angular grains, contain too much feldspar and other impurities to be used for refractories. Consequently quartzite is the chief source of high-grade ganister.

Approximately 80 per cent of the ganister of the United States is quarried in Pennsylvania, and the remainder in Wisconsin, Alabama, Colorado, Montana, Illinois, Maryland, and Ohio.

[a] Seaver, K., Manufacture and tests of silica brick for the by-product coke oven: Am. Inst. Min. Eng. Bull. 105, September, 1915, p. 1915.

[b] Seaver, K., Loc. cit.

NATURE OF DEPOSITS.

The quartzites, from which by far the larger proportion of ganister is quarried, are metamorphosed sandstones, the grains of which are firmly cemented together with silica. Most of the beds are greatly folded and contorted, are steeply inclined to the horizontal, and are commonly interbedded with thin shale bands. Some of the quarries are situated on the solid ledges, in which case the rock is shattered by blasting. In other places, notably in western Pennsylvania, in the vicinity of Mount Union and Point View, rock is obtained from loose surface fragments, known to quarrymen as "floe rock."

METHODS OF QUARRYING SOLID LEDGES.

STRIPPING.

In bench quarries, where the stripping is very light, the soil is usually shot down with the rock, and is later removed from the bench by wheelbarrows or dump cars along with other quarry waste, such as inferior rock or interbedded shales. The same method has been observed where the clay or gravel stripping is 6 to 10 feet thick. The efficiency of the method where heavy stripping is involved is seriously questioned. Where the rock fragments shattered by blasting are mixed with this accumulation of débris, considerable time is lost in separating the good material from the waste. Moreover, the soil must be loaded by hand into dump cars for removal from the quarry face. This slow and inefficient method of handling stripping may be allowed where only a small quantity of material must be handled, but where large quantities must be handled some other method should be sought. The suggestion is offered that some method of stripping ahead of quarry operations, and thus keeping the stripping out of the pit, would be more efficient. Teams and scrapers or drag-line scrapers are suggested as more rapid and cheaper methods of soil disposal if conditions are favorable for their operation. The consideration of the various methods of stripping described in a previous part of this report may offer useful suggestions to the ganister quarryman.

BLASTING AT QUARRY FACE.

The purpose of blasting is to break the rock into fragments ready for loading into cars and of such a size that they can be handled by one man. The method employed in solid ledges of quartzite is to drill a hole with a steam or air drill and then to squib it out with small 40 per cent dynamite charges, in order to obtain an opening of considerable size at the bottom of the hole. A charge consisting of 15 to 20 kegs of powder is then placed in the opening and discharged by fuse. A method of blasting without drilling may be

employed where beds of shale occur at intervals between the quartzite beds. A hole is punched into the soft shale with a bar, and small charges of dynamite are repeatedly discharged in the hole until an opening of considerable size and depth is obtained. A heavy charge containing a maximum of about 150 pounds of 40 per cent dynamite is placed in the opening and discharged by fuse. In one quarry of this type approximately 2,800 pounds of rock is moved for each pound of dynamite used, including subsequent shots. Considerably more rock could be moved for each pound of explosive employed if holes were drilled into the solid quartzite, but it is estimated that the additional cost of explosive used by the method now employed is more than compensated for by the saving of drilling costs.

METHOD OF MAKING SUBSEQUENT SHOTS.

Many of the rock fragments brought down by blasting at the quarry face are too large to be loaded into cars without further subdivision. The smaller masses may be broken by sledging, but blasting is required for the larger ones. For making subsequent shots either "block holes" or "mud caps" are used. For a block hole a hole is drilled several inches into the block with one of the smaller types of compressed-air drills, such as the hammer drill or the jackhammer. A stick or part of a stick of dynamite is placed in the hole and discharged by fuse. In order to cause a minimum interference with other quarry operations a number of blocks are drilled and charged, and the fuses lighted as nearly simultaneously as possible. The shots are therefore discharged in rapid succession, and the quarry gang may leave for places of safety and resume work with small loss of time.

For a shot with a "mud cap" a stick of dynamite with a fuse attached is placed on a block and covered with sand or clay, to confine the force of the explosion and to direct it toward the rock mass. For equal results much more dynamite is required by this method than by the "block-hole" method, whereas, on the other hand, the cost of drilling is saved. An experienced quarryman states that for equal results it requires seven or eight times as much explosive for shots by the "mud-capping" as by the "block-hole" method. By using compressed-air hollow-steel drills, which give efficient service and are operated by one man, it is probable that the "block-hole" method is the more economical.

METHOD OF LOADING ROCK.

The rock is broken up by blasting or sledging into pieces not exceeding sizes that one man can handle. The fragments thus obtained are loaded by hand into cars having a capacity of about 2½ tons.

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The smaller fragments are loaded with heavy-pronged forks made especially for this purpose.

TRANSPORTATION.

Loaded cars are usually hauled by mules. A tipple is constructed where the rock is dumped into bins or into railway cars for transportation to the silica-brick plants. Where the quarries are situated at high levels, gravity cableway-car systems are employed to carry the loaded cars to the tipples situated by railroad tracks at lower levels.

METHOD OF QUARRYING "FLOE ROCK."

NATURE OF FLOES.

At certain points in western Pennsylvania rivers have cut deep and steep-walled valleys through the ridges of quartzite. The removal by weathering of underlying softer materials has left the quartzite exposed. Frost action has broken this surface rock into masses of various sizes, which lie along the faces of the steep hills to maximum depths of about 25 feet. In places bands of this so-called "floe rock" several hundred yards wide extend for several miles along the river bluffs.

The quality of the floe rock is superior to that of the solid ledges in the same deposit, because, although the quartzite is extremely resistant to weathering, the impurities—consisting of iron, clay, or other materials—are less resistant, and consequently crumble or dissolve and are carried away. As the rock is broken into innumerable fragments, a vast surface area is exposed to the solvent effects of atmospheric agents, and a large part of the impurities, which would otherwise be present in the solid ledge, is removed.

BLASTING.

The only blasting required in quarrying rock of this type consists of block-hole shots or mud capping for the subdivision of the larger masses. It is estimated by one large company that 1 pound of dynamite used in mud capping is on an average sufficient for every 5 tons of stone quarried. It is to be noted, therefore, that blasting operations in floe-rock quarrying cost much less than in solid-ledge quarrying.

METHOD OF PLACING TRACKS.

The limited depth of floe rock requires quarrying over a wide area, and in consequence a somewhat elaborate system of trackage is demanded. Tracks are laid along the face of the hill, heavy grades being avoided wherever possible. Rock is loaded from the side of

the tracks adjacent to the upward slope of the bluff. When all the rock within convenient reach is exhausted, the track is placed at a higher or lower level, usually the former. The method of gaining access to one level from another is by "back switching"—placing the track on a moderate upward grade and projecting another track back from it in an opposite direction at a higher level. The first track is usually placed near the lower edge of the deposit, and the process of constructing zigzag branch tracks may be continued until the upper limit of the deposit is reached. The system of trackage is much more extensive, and therefore more costly, in floe-rock quarrying than in solid-ledge quarrying. In some instances several miles of tracks are employed, the maintenance and shifting of which require a gang of men constantly at work. For a quarry employing about 35 men in all, 6 or 8 men are required in transportation, including engineer, brakeman, track graders, repair men, etc. This item of operating cost, which is heavy, is somewhat compensated for by the extremely low expense for explosives.

METHOD OF LOADING ROCK.

If the masses are not broken to convenient sizes by the processes of nature, they are subdivided by sledging, mud capping, or block-hole shots to sizes suitable for hand loading, just as in solid-ledge quarrying. The rock is loaded into cars of 2 or 3 ton capacity. It is worked down toward the track for a space of 30 to 50 feet up the hillside, the distance depending on the steepness of the grade. It is not economical to strip the rock from a wide area to one track if it is necessary to employ helpers to roll the rock down to the loader, as rehandling is expensive. It is better to work up the hill a moderate distance, and then continue operations from a back switch at a higher level.

In working rock down from a steep hillside, care must be exercised to prevent the descent at one time of a large mass of rock fragments which would not only endanger workmen but might block or destroy the track. The rock is worked out in "pockets" 30 to 50 feet wide between which masses 10 to 15 feet wide are left untouched to serve as buttresses for the upper masses. In this manner masses of moderate extent are precipitated down the hill in succession, a method that is less destructive to equipment and less dangerous to workmen than where no such supports are left.

Where the tracks are built along steep hills, with railways or roads at their bases, it is imperative that rock fragments be not permitted to roll over the tracks and down the hills. Where it is necessary to throw down rock fragments in a mass of more than ordinary magnitude, a method of preventing an overslide is to place on the tracks a

row of steel cars loaded with stone. It is claimed that the rolling rock fragments are easily stopped in this way, and that they do little damage to the cars.

TRANSPORTATION.

Small locomotives or "dinkeys" are commonly used to transport the loaded cars from the working place and to return the empties. Trains usually consist of six to eight loaded cars. When rock is obtained from points at moderate levels above the manufacturing plants or main railway lines, it may be possible to bring the train of cars down to the desired destination by a continuous grade or by back switching. If this is possible, it is most desirable. Where quarries are at high levels, cable-car systems are required. Plate V, *B*, illustrates the cable-car system of a quarry near Point View, Pa. The track is 1,945 feet long.

Most cable-car systems are of the gravity type, with a steel cable which passes around a drum at the top of the incline, the loaded car being attached to one end and the empty car to the other, the empty car ascending as the loaded car descends. A three-rail system with a switch at the center is commonly used, although a track consisting of three rails above and two rails below the center switch is also employed. As there is at no time more than a single cable below the center, a two-rail track is sufficient for this part of the course, provided an automatic center switch is used. The speed of the car is governed by a powerful brake.

Some quarrymen, instead of employing a drum, prefer two sheaves, 5 to 6 feet in diameter, running in a horizontal plane. The cable runs around them in several turns in the form of a figure 8, and on the outer surface of the sheaves above the cable grooves wooden-faced friction brakes are operated by a lever. Usually loaded cars descend singly, although where operations are extensive they may descend in trains of two, three, or four cars.

UNLOADING.

The rock cars are mostly of the end-dumping type, and a suitable tipple is provided at the crushing plant for rapid unloading. Where further transportation by railway train is required, the tipple is so arranged that the rock may be dumped directly into railway cars, the latter usually being of the hopper-bottom type.

WASTE IN GANISTER QUARRYING.

Waste in ganister quarrying is occasioned mainly by imperfections in the rock, the chief of which are the presence of impurities and insufficient cementation of the individual grains. Clay is considered the most serious impurity, as it lowers the fusion point of the silica brick. Therefore all rock containing streaks or lenses of clay is thrown away. Rock is also condemned if it contains prominent iron

stains. A rock though pure may be of poor quality on account of softness. As pointed out in a previous paragraph, the softer rocks crush to rounded sandstone fragments, whereas those highly indurated crush to the more desirable angular fragments or splinters. Waste blocks are thrown away or utilized for filling low places or for grading tracks.

SAFETY AND HEALTH IN QUARRYING SANDSTONE.

For a description of safety problems connected with quarries, readers are referred to Bureau of Mines Technical Paper 111 entitled "Safety in Stone Quarrying."[a] Although this paper deals mainly with the problems presented in marble quarries, most of the suggestions offered are applicable to many other types of quarrying. It seems advisable, however, to include in a discussion of sandstone quarrying a brief discussion of the causes of quarry accidents most common in this type of quarrying and the means that may be employed to overcome them.

As a result of observations made by the author when visiting sandstone quarries, certain safety suggestions are offered in the following pages in the hope that sandstone quarrymen may be induced thereby to take whatever steps are necessary in order to reduce the number of quarry casualties.

According to statistics compiled by Fay[b] the total number of men employed in and about sandstone quarries in the United States in 1915 was 8,385. The number of men killed was 6, or 0.72 per 1,000 men employed; seriously injured 179, or 21.35 per 1,000; and slightly injured 252, or 30.05 per 1,000. Table 1 shows the number of men employed in and about sandstone quarries of the United States and the number of casualties for the five years 1911 to 1915. Table 2 shows, for the same five years, the number of fatalities, classified according to cause, and Table 3 gives, for the five years, the total number of fatalities due to the five chief causes.

TABLE 1.—*Number of men employed and number killed and injured in and about sandstone and bluestone quarries of the United States during calendar years 1911, 1912, 1913, 1914, and 1915.*

Year.	Total number of employees.	Number killed.	Number seriously injured.	Number slightly injured.	Widows.	Orphans.
1911	11,333	14	42	225	6	8
1912	9,753	8	61	251	4	7
1913	9,003	9	58	450	4	11
1914	8,642	9	68	360	5	9
1915	8,385	6	[c]179	252	4	3

[a] Bowles, Oliver, Safety in stone quarrying: Tech. Paper 111, Bureau of Mines, 1915, 48 pp.

[b] Fay, A. H., Quarry accidents in the United States during the calendar year 1915: Tech. Paper 165, Bureau of Mines, 1916, p. 32.

[c] In 1915 loss of time 14 days or more, in previous years 20 days or more.

TABLE 2.—*Number of men killed in and about the sandstone and bluestone quarries in the United States during the calendar years 1911–1915, with the fatalities classified according to cause.*

Year	In quarry.														Outside of quarry.												
	Falls or slides of rock or overburden.	Rock while loading at working face.	Timber or hand tools.	Explosives.	Haulage accidents.	Falling into quarry from surface, benches, or face.	Falling from hoists, derricks, ladders, etc.	Drilling accidents (by machine or hand drills).	Electricity (shock or burns).	Machinery (not including locomotives or drills).	Flying pieces of rock from sledging.	Stepping on nail.	Other causes.	Total in quarry.	Quarry cars or locomotives.	Railway cars or locomotives.	Machinery.	Explosives.	Falls of persons.	Boiler explosions.	Timber or hand tools.	Electricity (shock or burns).	Stepping on nail.	Horse or mule.	Other causes.	Total outside of quarry.	Grand total.
1911	2		(a)	1	3	5		(a)	.....	(a)	(a)	(a)	.....	11	.....	.....	1	.....	(a)	2	(a)	.....	(a)	(a)	.....	3	14
1912	2	.....	1	.....	1	1	.....	.....	.....	.....	1	.....	.....	6	.....	.....	2	.....	.....	.....	.....	.....	.....	.....	.....	2	8
1913	2	.....	.....	2	.....	3	1	.....	.....	.....	.....	.....	.....	8	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	.....	1	9
1914	4	.....	.....	2	1	1	.....	.....	.....	.....	.....	.....	.....	8	.....	.....	.....	.....	.....	.....	.....	.....	.....	1	.....	1	9
1915	2	.....	.....	1	1	.....	.....	.....	.....	.....	.....	.....	.....	4	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	1	2	6
Grand total	12		1	6	6	11		.....	.....	.....	1	.....	.....	37	.....	.....	5	.....	.....	2	.....	.....	.....	1	1	9	46

a Not listed as a separate cause in 1911.

TABLE 3.—*Total fatalities in sandstone and bluestone quarrying due to each of the five chief causes during the calendar years 1911–1915.*

Cause.	Number killed.	Percentage of total fatalities.
Falls of workmen	11	23.9
Falls of rock or overburden	12	26.1
Explosives	6	13.0
Haulage	6	13.0
Machinery	5	10.9
	40	86.9

The attention of quarrymen is especially directed to Table 3. It will be observed that falls of workmen, falls of rock or overburden, explosives, rock haulage, and machinery account for 40 out of the total of 46 fatalities, or 86.9 per cent of all the fatalities.

QUARRY STAIRS AND LADDERS.

Falls from derricks or into quarry pits constitute prolific sources of fatal accidents. Most of them are due to falls into quarry pits from benches or from the surface. It may be that many such accidents are due to carelessness, but the writer is convinced that they are due in part at least to unsafe means of access to quarry excavations.

As a rule, the means of access to sandstone quarries is inadequate and, in many cases, dangerous. Ladders are almost universally used, and stairs with handrails are almost unknown. The argument advanced against the use of stairs is that through continued excavation the position of the quarry face is frequently moved, and the expense of moving stairs is much greater than that of moving ladders. The expense of moving stairs is, however, probably much less than most sandstone quarrymen suppose it to be. Properly made quarry stairs are in rigid sections, which can be moved readily and secured in new positions with great facility. They are not only much safer than ladders but are more convenient. Ladders have been observed with fractured steps at least 80 feet above the quarry floor. It is suggested that quarrymen observe carefully the types of quarry stairs illustrated in Bureau of Mines Technical Paper 111.[a] It is probably true that a material reduction in the excessive number of quarry accidents due to these causes would be brought about if better equipment were provided.

DANGERS FROM ROCK SLIDES AT QUARRY FACE.

Falls of rock or overburden were responsible for more than one-fourth of all the fatal quarry accidents during the five-year period 1911 to 1915. The dangers from rock slides are considered under the

[a] Bowles, Oliver, Op. cit., pp. 16–17.

present heading and those due to falls of overburden in a following section.

The danger of slipping of undisturbed rock in the quarry wall is possible under certain conditions only. Where beds are steeply inclined toward the quarry pit and interbedded with thin, slippery clay seams, the rock may slip on these beds. The removal of the supporting mass of rock in the process of quarrying may permit the unstable rock to slip down into the pit impelled by its own weight only, or slipping may be induced by loading such rock with quarried blocks or waste material. The motion is usually gradual at first, and if careful watch is kept for lateral displacement the danger of a slide may be recognized in time to avoid accident.

The greatest dangers from rock slides at the face are in quarries where rock is produced for crushing purposes. The quarry face is shattered and thrown down by explosives and, consequently, is in a very unsafe condition if adequate precautions are not taken.

A safe method employed in a crushed-rock quarry near Pittston, Pa., is noteworthy. The regular gang quits work at 4.30 p. m., and thereafter six reliable men roll down loose rock ready for the next day's work. Every fragment that appears to be in danger of rolling down is sent to the bottom. If during the day the process of removal disturbs other masses and renders them unsafe, men are sent to roll them down. One accident only, and that of a minor character, is said to have occurred in this quarry in the past three years.

Where the quarry face is high and precipitous, a workman may be let down from the top by means of a rope to throw down loose fragments with a bar. Where similar precautions are not taken, accidents are likely to be of frequent occurrence.

In ganister quarries of the floe-rock type the greatest risks are due to rock slides. The mass of loose rock is removed by working upward from the lower edge, and in consequence the support of the upper-rock fragments is constantly being removed. The method of working out the rock in pockets as described in the discussion of ganister quarrying obviates a large share of the danger.

DANGERS FROM FALLS OF OVERBURDEN.

One of the most prolific sources of danger in sandstone quarries is the falling of overburden into the quarry pit. In at least one-seventh of the quarries visited by the author the overburden walls are so steep and so close to the rock face that there is constant danger of material falling from them into the pit. Where excavations are of considerable depth, the dangers are correspondingly greater than where they are shallow. An overburden consisting of gravel and soil containing many bowlders of a few pounds weight or larger is probably the most dangerous form if the overburden is steep and

close to the pit, as the crumbling of the finer parts allows the bowlders to roll down, and their size is sufficient to cause serious or fatal injury, even though they may fall only a few feet. A clay bank is less treacherous.

The obvious means of preventing such dangers is to make the overburden walls less steep, and to strip some distance ahead of quarry operations, leaving a stripped surface to collect the falling material. A fence or barrier along the edge of the pit will increase the safety.

When overburden walls are 50 to 60 feet high, the expense of removal of stripping will be so high that it will prohibit stripping ahead of operations to a sufficient distance to render the quarry safe from falls of débris. Great height also renders such walls exceptionally dangerous. At one quarry having high overburden walls a secure fence constructed of plank is so placed that it intercepts and holds all falling material (Pl. VI, *C*). The construction of some such barrier seems to be imperative in quarries of this type. The adoption of tunneling in quarries with exceptionally heavy stripping removes the danger of falls of overburden, but at the same time involves the danger of roof falls, although with properly constructed tunnels the roof falls would probably involve much less risk than that to which many quarrymen are at present exposed.

Beds of badly shattered rock, such as occur commonly in the upper part of a deposit, may also constitute sources of great danger. When water penetrates the cracks and freezes therein, the cracks are opened and the mass becomes more and more unsound. Rock falls are most likely to occur in the springtime when thawing sets in.

DANGERS IN BLASTING.

Safety in blasting and in handling explosives is discussed in detail in Bureau of Mines Technical Paper 111.[a] The rules given are applicable to all types of sandstone quarries. The more common risks in connection with blasting as observed in sandstone quarries may be briefly noted.

The use of an iron tamping rod has been observed. A metal tamping rod should never be used under any circumstances, and its use involves special dangers in sandstone, as the metal is liable to strike sparks from the quartz. A wooden rod should be used.

The location of an explosives magazine too close to blasting operations is dangerous, as rock fragments hurled by blasting may strike it and cause detonation of the contents.

The failure of quarry workmen to seek sufficient shelter from a blast causes a number of accidents. In the case of heavy blasting

[a] Bowles Oliver, Op. cit., pp. 18–25, 32–33.

with dynamite the fragments may go to a great height and fall almost vertically. Whenever possible shots should be fired before or after working hours, when workmen are remote from the locality. When fired at other times sufficient warning should be given, adequate shelters should be provided, and there should be firm insistence upon obedience to safety rules by every workman.

The carrying of percussion caps in the same receptacle with explosives is to be condemned, as the accidental detonation of a cap would detonate the explosives.

Great care should be exercised to prevent spilling of black blasting powder on the rock surface, as boot nails are liable to strike fire on the quartzose rock and to ignite the scattered fragments. There is great danger of fire being transmitted to larger charges of explosives in this manner.

DANGERS IN ROCK TRANSPORTATION.

RIDING IN CARS.

As a rule it is dangerous to ride in quarry cars, although riding in empty cars may under certain circumstances be permissible. Where the working place is at an elevation of several hundred feet above the workmen's dwellings, after cars, cables, attachments, and hoisting gears have been carefully inspected and found to be safe, ascent may be made by cable cars to the working place. Promiscuous ascent at all times during the day should, however, be discouraged. Riding in cars loaded with rock should under no circumstances be allowed. When employees are found riding on loaded quarry cars one Pennsylvania company inflicts a fine of $5 for each offense.

POOR EQUIPMENT.

Uneven and insecure tracks are a source of danger, as cars or locomotives may be derailed with serious consequences. At one quarry where loaded cars descend a gentle grade by gravity and empty cars are returned by hand, the tracks are of only 2-foot gage. Where irregularities in the track cause cars to rock from side to side there is great danger of their overturning. A wider gage would, in this and similar cases, render transportation much safer.

More adequate brake systems are to be desired in many quarries. Commonly a bar is placed in the frame of the car and pressed against the wheel as a lever. In other quarries a stick is placed between the spokes of a wheel, and when it meets the frame the wheel is prevented from turning, and thus acts as a brake. Insertion of a stick while the car is running is a risky operation, and the attempt is frequently unsuccessful, with the result that the car runs

away. In one quarry where a brake of this type is employed, within a period of two hours the writer observed three cars off the track, two runaway empty cars, and one collision of a loaded car with empties.

DANGERS FROM CABLE CARS.

One of the greatest risks connected with cable cars running on inclined tracks is the danger of cars starting at the top of the incline before the cable is attached. A runaway car loaded with several tons of stone is a most serious menace to life and is destructive to equipment. In many quarries cars are hauled to the top of the incline by a cable or, more commonly, by means of a mule. While the necessary change in cable attachment is being made the wheels may be blocked with a piece of wood or stone placed on the rail. This is not a secure means of holding the car, as the block may slip or be accidentally removed, permitting the car to start before the controlling cable is attached. An efficient means of preventing such accidents was observed at a Pennsylvania ganister quarry and is shown in figure 19. It consists of a timber block which rises from a depression between the rails and meets the buffer of the car. When the car is ready to descend, the timber, controlled by a lever, descends into a pit out of the way.

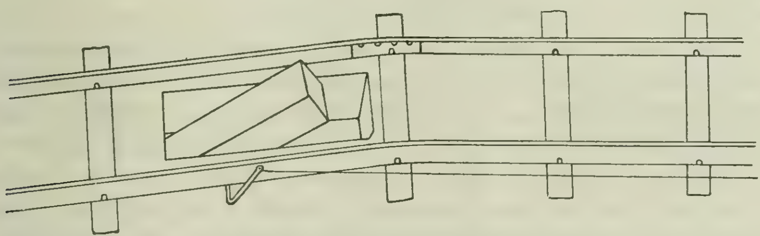

FIGURE 19.—Timber buffer to prevent loaded car from running down incline before cable is attached.

As an additional precaution a derail is placed a short distance from the top of the incline. With a three-rail system the derail should be on both outer rails. To be most effective it should slide toward the center rail. It thus forces the car outward, directs it away from the track, and causes it to travel where it can do the least damage. The derail is thrown until the car begins to descend and until its safe control is recognized; the derail is then thrown into place by a lever before the car reaches it.

It is unsafe to stand near inclined tracks where loaded cars are descending. Not only is there the ever-present danger of the cars jumping the tracks, but rock masses may roll from the cars and fall beside the tracks.

SAFETY DEVICES ON TRANSFER AND GANG CARS.

Workmen's hands are frequently injured by transfer-car wheels where they project above the car frame. One Ohio company has overcome this danger by constructing simple wheel guards from discarded belting.

When a block is sawed into thin slabs the removal of the gang car involves some risk, as the slabs are in vertical position, and may fall over upon the men employed. One standstone company has met this danger by placing at either side of the car a socket by which a plank is held in vertical position.

DANGER ON WAGON ROADS.

Transportation by wagon road at some bluestone quarries involves considerable danger where roads are cut in soft rock on steep hillsides flanking river channels. The roads in many places are very narrow and border precipitous hills. Especially in the springtime, when frost is leaving the rock, their support is of doubtful security.

Many of the bluestone quarry roads are also rough and precipitous, 25 per cent grades being not uncommon. Merrill[a] states that the driving of wagons loaded with rock down these steep grades is attended with much danger, and results in many fatal accidents.

DANGERS IN HOISTING.

The most common source of accident incidental to hoisting in sandstone quarries appears to be due to attempted adjustment of cables or blocks while they are in motion. The attempt to shift the position of a cable or to take a twist or kink out of a cable while it is in motion, or to prevent the swinging or rotating of a block after it is raised from the floor, frequently results in an accident. Similar risks are incurred where men pass beneath or near suspended blocks. If the hoist cable requires adjustment, a signal should be given to the hoist man to stop until the proper adjustment is made. If control of a hoisted block is desired, a rope should be attached to it, so as to permit control at a safe distance. Points beneath or near suspended blocks are danger zones and should be avoided.

DANGERS AROUND MACHINERY.

When it is desired to suspend operation of a drill or channeling machine, for purposes of adjustment, it is important that the steam or air be entirely shut off. An instance is known where access of steam into the cylinder of a drill caused the piston to descend, and

[a] Merrill, J. H. M., Quarrying of bluestone and other sandstones in the Upper Devonian of New York State: State Museum Bull. 61, 1903, p. 15.

a man's foot was crushed by a wrench attached to a nut on the drill bar.

It is an extremely dangerous practice to attempt repair or adjustment of running machinery, especially around gears or belts. A workman once lost an arm in attempting to tighten a nut situated just over the heavy gear wheels of a rock crusher. A ragged sleeve was caught in the gears and drew the arm in with it. This suggests also the great danger involved in wearing loose clothing while working around moving machinery. Gears, flywheels, and belts should have adequate guards.

Inspection of boilers and of compressed-air tanks should be frequent and thorough. An explosion of a compressed-air tank resulted in a fatality in 1915. The tank had been patched, but seemingly the weld was imperfect, for it burst as soon as the tank was used. This accident suggests a desirable modification of present laws in many States. It should be unlawful to use boilers or compressed-air tanks after repairs until a hydraulic test has demonstrated that no flaws or weaknesses exist.

It is customary at some quarries where locomotive cranes are employed for lifting blocks of stone to clamp the rear wheels to the track, so that when a heavy block is raised the machinery will not overbalance. The danger involved in this method consists in the inability of the operator to judge the severity of the strain exerted on the clamps; and if the strain is sufficient to break any part of the equipment holding the machinery down, a sudden and serious accident may easily result. It is much safer to leave the wheels unclamped. If an attempt is made to lift a block of too great weight, the moment the wheels are raised from the track hoisting may be discontinued, the prudent policy being to leave the handling of such blocks to more stable equipment.

OCCUPATIONAL DISEASES.

It is generally recognized that tubercular or other lung trouble may result from continued breathing of an atmosphere containing silica dust.[a] The effect of rock dust is an important consideration, therefore, in every process connected with sandstone quarrying or finishing plants, as sandstone consists almost entirely of silica. Devices for keeping dust away from workmen are desirable, particularly in connection with those operations that grind the rock into a fine powder. A convenient device on compressed-air drills is an opening through which air passes and blows downward in such a manner that it prevents a large share of the rock dust from ascending to the driller's face.

[a] See Lanza, A. J., and Higgins, E., Pulmonary disease in the Joplin district, Mo., and its relation to rock dust in the mines: Tech. Paper 105, Bureau of Mines, 1915, 48 pp.

Most plants that have lathes for turning down grindstones are provided with powerful suction fans, which draw the dust from the pits beneath the stones and conduct it through pipes to places where it can do no harm. Dust may also be kept down by working the stone wet, though this method seemingly is not used.

Many crushing and pulverizing plants are very dusty and are provided with no adequate means of removing the dust. Suction fans are desirable in such places.

Whenever the introduction of new machines or new and improved methods is contemplated the production of rock dust involved and the provision for adequate means of overcoming its effects must be seriously considered.

DISTRIBUTION OF SANDSTONE IN THE UNITED STATES.

GENERAL DISTRIBUTION.

The sandstones of commercial value available in the United States are of various types and represent many different geologic formations. Almost every State in the Union is supplied with sandstone that may be used for building or other purposes. The great bulk of available sandstone falls in one or another of these four great geologic systems: Carboniferous, Triassic, Cretaceous, and Tertiary. Sandstones of these systems are found in certain well-defined geographic areas. The areas and the characteristic systems may be briefly outlined as follows:

The eastern area comprises those States that border the middle Atlantic seaboard, where brownstones of Triassic age form a belt roughly paralleling the coast through Massachusetts, Connecticut, northern New Jersey, southern Pennsylvania, central Maryland, and east central Virginia, terminating in North Carolina. This is an important belt, as it is adjacent to the principal eastern cities. Triassic sandstones occur also in some of the Rocky Mountain States.

The second area comprises the Mississippi River Basin, exclusive of the Gulf region, the headwaters of the river, and its larger tributaries. In this area, the gray and buff Carboniferous sandstones prevail, attaining their maximum importance in Ohio.

The western area includes the Rocky Mountain and Pacific States. Cretaceous and Tertiary deposits constitute the chief source of sandstone in this region. Available sandstones are widely distributed and abundant, though in large measure undeveloped.

The fourth well-defined region includes the Southeastern and Gulf States, except northern Mississippi, Alabama, and Georgia, which are included in the Mississippi Basin region. In this area Tertiary deposits constitute practically the entire sandstone resources. As a source of building stone this area is the least important of the four outlined.

It is noteworthy that Cambrian and Ordovician sandstones are utilized in several States in the Mississippi River basin and in the region of the Great Lakes, but constitute a source of commercially available sandstone in few other localities. Cambrian, Silurian, and Devonian sandstones prevail in New York State. Huronian quartzites now used are confined almost exclusively to South Dakota and Minnesota.

DISTRIBUTION BY STATES.

The distribution of available sandstones of commercial value in the various States is briefly given in the following pages. The States follow each other in alphabetical order, with the exception of the New England States, which are grouped together and considered under the heading "New England."

ALABAMA.

Sandstones in Alabama are chiefly of Cambrian and Carboniferous age. Those of coal-measure (Carboniferous) age are exposed in Walker, Cullman, and Tuscaloosa Counties. The Hartselle (Lower Carboniferous) sandstones appear in Colbert County, and the Weisner (Cambrian) sandstone in Calhoun County.

ARIZONA.

Red, brown, and white sandstone of good quality abounds in the Grand Canyon of the Colorado River, but is for the most part inaccessible. The best-known sandstone in Arizona is in the Moencopie formation, probably of Permian age, outcropping near Flagstaff in Coconino County and also in Navajo County. A Triassic sandstone has been quarried in Yavapai County. Sandstone has also been quarried in Mohave County and quartzites near Bisbee in Cochise County, near Globe in Gila County, and near Morenci in Greenlee County.

ARKANSAS.

Sandstones of Pennsylvanian (Upper Carboniferous) age are abundant in the northwestern half of the State. The best rocks are in the Boston Mountain region and to the north and west of it. They have been quarried to some extent in Independence County.

CALIFORNIA.[a]

Sandstones of serviceable character for building purposes cover wide areas in the Coast Range and are exposed along the borders of the northern and central parts of the Sierra Nevada. They are

[a] For California and a number of other States, Burchard's discussion of quarry distribution was consulted; see Burchard, E. F., Mineral resources of U. S. for 1911, U. S. Geol. Survey, 1912, pp. 741–834; Mineral resources of U. S. for 1912, U. S. Geol. Survey, 1913, pp. 709–818; and Mineral resources of U. S. for 1913, U. S. Geol. Survey, 1914, pp. 1285–1410.

mostly of Cretaceous and Tertiary age. Deposits of note occur in Colusa, Los Angeles, San Luis Obispo, Santa Clara, and Ventura Counties. Various colored sandstones, which have as yet attracted little attention, are exposed in Amador, Contra Costa, Marin, Santa Barbara, Shasta, and Siskiyou Counties.

COLORADO.

In the Lower Triassic (Red Beds) of western Colorado are three strata of good sandstones, the lower or Manitou being the most important. The rocks have been quarried in Larimer and Boulder Counties. Cretaceous sandstones are also available in Boulder County. An attractive red sandstone of Triassic age occurs in Jefferson County. Gray and buff sandstones of Laramie age are exposed in Fremont County. Sandstone is also obtained in Las Animas County,[a] and stones suitable for grindstones and pulp stones are said to occur in Gunnison and Boulder Counties.

DELAWARE.

No sandstones are quarried in Delaware. Cretaceous and Tertiary deposits contain various sandy beds which are for the most part unconsolidated.

FLORIDA.

Little structural sandstone is available in Florida, though incoherent sands are widespread. Coastal Plain sandstone has been quarried in Levy County.

GEORGIA.

Sandstones 800 feet thick occur in the Paleozoic rocks of the Cumberland Plateau in the extreme northwest of the State. Silurian sandstones are abundant in Murray County, and buhrstone (used for millstones) of Miocene age occurs in Decatur, Early, Burke, and Screven Counties. Novaculite, which is used for oilstones and whetstones, is said to occur in various places in McDuffie, Oglethorpe, Troup, Meriwether, Heard, and Lincoln Counties. Sands from various parts of the State are utilized.

IDAHO.

Available sandstones occur near Boise in Ada County and near Dingle in Bear Lake County. The former occurrence is of Tertiary age and the latter is Jurassic or Triassic.

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[a] For more details concerning the sandstone resources of Colorado, see Merrill, G. P., Stones for building and decoration, 1910, pp. 132–135.

ILLINOIS.

Pennsylvanian sandstones in the western and southern parts of the State constitute the most important quarryable rock. Ordovician sandstones in the northwestern counties are used to some extent, but those of the Fox and Illinois River valleys are so friable that they are used only for glass sand.

INDIANA.

Sandstone deposits of commercial value are not extensive in Indiana. They occur in the Pennsylvanian series in the western and southern part of the State, in the Mississippian series in the southern counties, and in the Silurian series in the northeast. Sandstones are quarried to a limited extent in Fountain, Harrison, Jasper, Perry, Spencer, and Wabash Counties.

IOWA.

The more important sandstones of Iowa are in the Pennsylvanian (Upper Carboniferous) series in the southern and central parts of the State. The sandstones of Scott, Webster, Marshall, Marion, Mahaska, Lee, Keokuk, Jasper, Des Moines, and Decatur Counties are chiefly Pennsylvanian. The exposures of Tama, Jones, Hardin, Fayette, Clayton, and Black Hawk Counties are chiefly Mississippian, Devonian, and Silurian.

KANSAS.

The geologic formation that constitutes the chief source of sandstone is the Pennsylvanian, which occupies the eastern one-fourth of the State. In the Cretaceous and Tertiary beds to the west a limited amount of sandstone is available.

KENTUCKY.

Sandstones of Mississippian age occur in Rowan County in the northeast, and Rockcastle County in eastern central Kentucky. Sandstones of Pennsylvanian age are exposed in Knox and Bell Counties in the south, and in Muhlenberg, one of the western central counties.

LOUISIANA.

Ferruginous sandstones of Eocene age occur in most of the hills of northern Louisiana, and siliceous sandstones of Grand Gulf (Oligocene) age in southern Sabine Parish, and near Boyce, Lena, and Harrisonburg. The sandstones are for the most part inferior.

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MARYLAND.

The best structural sandstone of Maryland is the "Seneca Red" of Triassic age, which outcrops at a belt through Carroll, Frederick, and Montgomery Counties. Of Paleozoic sandstones the Montery and Tuscarora formations, outcropping in Allegany and Washington Counties, are the most important, though sandstones of the Pottsville and Pocono formations, which may be utilized to some extent, are exposed in Garrett and Allegany Counties. Two parallel belts of Cambrian quartzites outcrop in Frederick and Washington Counties. Scattered areas of quartz schist of uncertain age outcrop in eastern Maryland.[a]

MICHIGAN.

In Houghton, Baraga, and Marquette Counties on Lake Superior in the northern peninsula, are sandstones similar to the brownstones of Wisconsin and Minnesota that occur near Duluth. They are of Potsdam (Cambrian) age or older. Lighter colored sandstones of Carboniferous age are exposed in the southern peninsula in Eaton, Huron, Ionia, Monroe, and Ottawa Counties.

MINNESOTA.

The Sioux quartzite of Huronian age is exposed prominently in southwestern Minnesota, in Rock, Pipestone, and Nicollet Counties, in all of which quarrying has been done. Other outcrops are in Watonwan and Cottonwood Counties. These outcrops represent an eastward extension of the deposit in South Dakota.

Sandstone that is regarded by some as Cambrian and by others as Keweenawan in age outcrops along the bluffs of Kettle River in Pine County, and is quarried extensively.

What is known as the Fond du Lac brownstone of probable Keweenawan age outcrops extensively near Duluth, in St. Louis County. It is a westward extension of similar brownstone in northwest Wisconsin.

Cambrian and Ordovician sandstones are abundant in Minnesota, particularly along the Mississippi River and the lower Minnesota River valleys, but most of them are incoherent.

MISSISSIPPI.

Mississippian sandstones are exposed in Tishomingo, Prentiss, and Itawamba Counties. The Tallahatta buhrstone of Lower Tertiary age outcrops in Holmes, Attala, and Lauderdale Counties; and

[a] For further information regarding Maryland sandstones, see Mathews, E. B., Md. Geol. Survey, vol. 2, 1898, pp. 199–212.

the Grand Gulf (Middle Tertiary) sandstone appears principally in Hinds County. Sandstone has been quarried in past years in Holmes County.

MISSOURI.

Carboniferous rocks in the northwestern half of Missouri constitute the chief source of quarryable stone. Rock exposures occur in Bates, Calloway, Clark, Henry, Howard, Johnson, Putnam, Saline, Schuyler, St. Clair, and Barton Counties. Sandstone of Cambrian and Lower Ordovician age is available in Barton, St. Genevieve, Franklin, and Hickory Counties. The friable St. Peter (Ordovician) sandstone is quarried for glass sand principally in Franklin, Jefferson, and St. Charles Counties.

MONTANA.

The extensive sandstone deposits available in Montana are chiefly those of Cretaceous and Tertiary age, east of the Rocky Mountains. The best known sandstone is that of Yellowstone County, quarried near Columbus. Available deposits occur also in Cascade, Chouteau, Gallatin, Beaverhead, Carbon, Custer, Fergus, and Sweet Grass Counties. Quartzites of superior quality are reported from Beaverhead and Missoula Counties. Tertiary volcanic ash, sufficiently consolidated to make building stone, occurs in parts of Beaverhead, Gallatin, Rosebud, Missoula, and Ravalli Counties.

NEBRASKA.

Pennsylvanian (Upper Carboniferous) sandstone is available in eastern Nebraska and Cretaceous and Tertiary sandstones are sufficiently indurated for building purposes in various places. The chief production is from Greeley and Sarpy Counties. Many friable sandstones are available for sand production.

NEVADA.

The sandstones of Nevada are all of Recent geologic age, and are for the most part weak, though serviceable stone has been quarried in several places. Fairly strong and coherent stone is exposed in Ormsby, Churchill, Humboldt, and Elko Counties.

NEW ENGLAND.

The sandstones of New England most utilized are confined to the brownstones of Triassic age along the Connecticut River Valley in Connecticut and Massachusetts. They are worked most extensively at Portland, Middlesex County, Conn., and at East Long Meadow

in Hampden County, Mass. A small area of sandstone and conglomeratic sandstone, the "Roxbury pudding stone," southwest and south of Boston, is quarried for local uses and has been much used for foundation stone and for churches and other buildings. Good Devonian sandstone is said to occur in Washington County, Maine.

NEW JERSEY.

Sandstones, including brownstones and conglomerates, outcrop in many places throughout the northern half of New Jersey. The brownstone of Triassic age is the most abundant, occurring in Bergen, Hudson, Essex, Passaic, Somerset, Huntingdon, and Merces Counties. Flagstones outcrop in Huntingdon, Warren, and Sussex Counties, and argellite in Mercer and Huntingdon Counties.

NEW MEXICO.

Available sandstones are found in the Cretaceous system, which is exposed chiefly in the northeastern part of the State, and in the Carboniferous system in the central and southern area. Production has been reported from Rio Arribo, Colfax, Lincoln, Mora, San Miguel, and Valencia Counties.

NEW YORK.

The so-called "bluestones" of Devonian age constitute an important sandstone resource in New York State. They occur chiefly along the Hudson River, in Albany, Green, and Ulster Counties, and along the Delaware River in Sullivan, Delaware, and Broome Counties. Other outcrops are in Wyoming County and in the counties bordering on Pennsylvania from Chemung westward.

The largest sandstone quarries in the State are in the Medina formation of western New York. The chief deposits are in Orleans County, though rock also appears in Niagara and Monroe Counties.

The Potsdam sandstone of Upper Cambrian age occurs chiefly in Clinton, Franklin, St. Lawrence, and Jefferson Counties, in the northern Adirondacks.

"Hudson River" sandstones occur in the Hudson River Valley from Glens Falls south into Orange County, and in the Mohawk Valley as far west as Rome. The Shawangunk conglomerate or grit which lies immediately above the "Hudson River" group is exposed in Ulster and Orange Counties. The Clinton sandstone outcrops along the Mohawk Valley in Herkimer and Oneida Counties.[a]

[a] For a more detailed discussion of sandstone distribution in New York, see Newland, D. H., Mining and quarry industry in New York State: State Museum Bull. 178, 1915, pp. 71–75.

NORTH CAROLINA.

The economic sandstones of North Carolina are all of Triassic age. They occur in two parallel belts running in a northeasterly direction. The northern and smaller belt is in Stokes and Rockingham Counties; the southern belt traverses Anson, Moore, Chatham, Wake, Durham, and Orange Counties.[a]

NORTH DAKOTA.

Sandstones sufficiently indurated for building purposes are not abundant in North Dakota. A Cretaceous sandstone outcrops in Emmons County and a Tertiary sandstone in McHenry County.

OHIO.

The extensive sandstone deposits of Ohio are in the Mississippian or Lower Carboniferous and the Pennsylvanian or Upper Carboniferous series.

Exposures of Mississippian age appear in a broad belt which extends from Portsmouth on the Ohio River, in the southern part of the State, almost due north to Norwalk, in Huron County, and from there eastward to the northeastern corner of the State. The lower member of the Mississippian, the Bedford stratum, contains little sandstone of commercial value except in the vicinity of South Euclid in Cuyahoga County. Above this is the Berea sandstone, in which the largest quarries in the State are situated. It is quarried most extensively in Lorain and Cuyahoga and to a lesser degree in several other counties to the south. The Cuyahoga formation, which lies above the Berea and is separated from it by the Sunbury shales, contains quarryable sandstones which are worked to a considerable extent in Scioto County in southern Ohio.

The Pennsylvanian sandstone outcrops throughout the eastern third of the State, except the eastern extension of the Mississippian formation at the north. Valuable rock is exposed in Holmes, Stark, Columbiana, Jefferson, Carroll, Tuscarawas, Harrison, Belmont, Guernsey, Muskingum, and Washington counties. It is quarried in many places.

A limited area of Silurian sandstones occurs in the western part of the State.[b]

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[a] For details, see Watson, T. L., Laney, F. B., and Merrill, G. P., The building and ornamental stones of North Carolina: State Geol. Survey Bull. 2, 1906, pp. 216–236.

[b] For more details of the distribution of sandstone in Ohio, see Bownocker, J. A., Building stones of Ohio: State Geol. Survey ser. 4, Bull. 18, 1915, pp. 65–149.

OKLAHOMA.

Sandstone is the most widely distributed building stone in Oklahoma. In the south, Cambrian sandstone outcrops in Murray, Johnston, and Pontotoc Counties. The best sandstones are those of Pennsylvanian age which occupy the eastern half of the State and outcrop in nearly every county in this region. The Permian sandstones of the western half of the State are mostly interstratified with the Red Beds and are for the most part soft. Cretaceous sandstones are exposed in Bryan, Marshall, Choctaw, and McCurtain counties in the southeast and near Kenton, in Cimarron County, in the extreme northwest.

OREGON.

The economically important sandstones of Oregon are of Tertiary age and are exposed along the coast range. Deposits of sandstone are found in practically all the coast counties south of Portland. Available sandstones are exposed in the following counties: Lincoln, Linn, Multnomah, Washington, Benton, Lane, Douglas, Jackson, Coos, Tillamook, and Marion.

PENNSYLVANIA.

Sandstones are widely distributed in Pennsylvania and are of widely different types. Bluestone occurs chiefly in Bradford, Susquehanna, Wayne, and Wyoming counties in the northwestern part of the State. Brownstone of Triassic age extends westward from New Jersey through parts of Bucks, Berks, Lebanon, and Dauphin Counties. Sandstones of Carboniferous age outcrop in many places in the southwestern counties. Quartzites of Carboniferous age are quarried in Carbon County, near White Haven, and quartzites of Medina age are exposed abundantly in Huntingdon and Blair Counties, where they are quarried for ganister. Sandstones are abundant in many parts of the Appalachian region, but are for the most part accessible only with difficulty.

SOUTH CAROLINA.

The sandy strata of South Carolina are chiefly in the form of unconsolidated sands. Glass sands occur in Barnwell and Clarendon Counties, and sand for sand brick, molding, and building in Cherokee, Abbeville-York, and Edgefield-Chesterfield zones of the Crystalline area.[a]

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[a] Sloan, Earle, Catalogue of the mineral localities of South Carolina: South Carolina Geol. Survey, Bull. 2, ser. 4, 1908, pp. 249–364.

SOUTH DAKOTA.

The sandstone deposits of South Dakota are confined to the southeastern part of the State and the Black Hills region of the west. The Sioux quartzite of Huronian age outcrops extensively in Minnehaha, Lincoln, Moody, Lake, McCook, Turner, and Hanson Counties of the southeast. It is a resistant and durable rock.

The sandstones of the Black Hills region include the Minnelusa (Carboniferous) sandstone, which is available for quarrying in Meade and Lawrence Counties, the bright-colored Jurassic sandstones, which may be used to a limited extent, and the Dakota (Cretaceous) formation, which is the most important source of building sandstone in the region. The Dakota sandstones are most accessible in Fall River, Pennington, and Lawrence Counties.

TENNESSEE.

The best sandstone in Tennessee is the Bon Air (Pennsylvanian), which caps the western part of the Cumberland Plateau. Clinch Mountain (Lower Silurian) sandstones appear in mountain crests of eastern Tennessee, and the Chilhowee (Cambrian) quartzites are also exposed in the eastern part of the State. Sandstones have not been widely used, partly because many of them are inferior in quality and partly because limestones are more widespread and available.

TEXAS.

Northwest of the Quaternary belt, which borders the Gulf Coast of Texas, are three parallel belts of Tertiary rocks, which reach nearly to Greenville at the north and to within a few miles of San Antonio at the south. Within this belt available sandstones are found in numerous localities, particularly in Lavaca, Fayette, Burleson, Grimes, Polk, and Tyler Counties. Northwest of the Tertiary zone is a broad belt of Cretaceous, Pennsylvanian, and Permian rocks which includes central Texas. Sandstones are exposed in this area in Tom Green, Palo Pinto, Lampasas, Burnet, Eastland, and Ward Counties. Cambrian and Ordovician sandstones are quarried for local uses, but the outcrops are of small extent.

UTAH.

In the Great Basin ranges of the western half of Utah and in the Wasatch Mountains at the eastern side of the Great Basin are Paleozoic quartzites, which have been little utilized up to the present time. Mesozoic sandstones abound in the north central part of the State from Thistle Junction northward, and Tertiary sandstones at scattered points in the eastern half of the State. The Nugget (Meso-

zoic) sandstone has been quarried at Emigration Canyon, in Salt Lake County; at Park City, in Summit County; and at Diamond Fork Canyon and Thistle, in Utah County. Tertiary sandstone also has been quarried in Utah County.

VIRGINIA.

The sandstones of greatest economic importance in Virginia are those of Cretaceous and Triassic age. The Cretaceous sandstones appear along the western margin of the Coastal Plain. For the most part they are not sufficiently consolidated for building purposes. Triassic sandstone appears in a southern extension of the New England-Pennsylvania-Maryland belt, on the Piedmont Plateau, the principal exposures being in Prince William and Fauquier Counties.

In the Appalachian Mountain region Cambrian sandstones occur in Augusta County and Carboniferous sandstones west of the Blue Ridge Mountains. They are most accessible in southwestern Virginia.

WASHINGTON.

Sandstones of Cretaceous age occur on islands in San Juan County, and Tertiary sandstones around the borders of Puget Sound and on the slopes of the Cascade Mountains. Older sandstones occur on the eastern slopes of the Cascades at the north. Sandstone development has been confined largely to regions having efficient means of transportation, chiefly water transportation. The most available sandstones are in Ferry, Kitsap, Pierce, San Juan, Thurston, Whatcom, and Yakima Counties.

WEST VIRGINIA.

Sandstones are abundant in West Virginia and have been quarried in many counties throughout two-thirds of the State. The more important sandstones are of Pennsylvanian (Upper Carboniferous) age and consist of beds in the Dunkard, Monongahela, Conemaugh, Alleghany, and Pottsville formations of this series. The number of different beds from which sandstone may be obtained is noteworthy.

Mississippian (Lower Carboniferous) massive sandstones have been quarried in Preston and Monroe Counties. They are hard and durable, but not readily accessible.

Devonian sandstone of good quarryable quality has been described only from near Rowelsburg in Preston County. Upper Silurian sandstones have been quarried for glass sand in Morgan County.[a]

[a] For details of the sandstone quarrying industry of West Virginia, see Grimsby, G. P., W. Va. Geol. Survey, vol. 4, 1909, pp. 355–558.

WISCONSIN.

Sandstones of Potsdam (Cambrian) age, or older, form a curved belt extending from the northeastern part of Wisconsin near Menominee southwestward and then northwestward to the St. Croix River. This is known as the southern Potsdam belt. A northern belt known as the Lake Superior brownstone, skirts the south shore of Lake Superior, and is quarried chiefly in Bayfield County. The St. Peter (Ordovician) sandstone forms a narrow strip extending in a southerly and westerly direction from the Menominee River. Part of it is loosely consolidated.

WYOMING.

Sandstones are widespread in Wyoming and are of fair quality. They have been developed more extensively than any other building stone in the State. They are of many different colors, and are available from various geologic formations. Cambrian quartzites have been quarried in Carbon County, and Carboniferous sandstones east of Laramie in Albany County, and near Aladdin in Crook County. A red sandstone, probably of Permian age, has been quarried northwest of Cheyenne in Laramie County. A sandstone, probably of Cretaceous age, occurs south of the latter deposits. Grayish-white sandstones that are probably Cretaceous occur in Weston, Bighorn, Fremont, and Uinta Counties. Buff Tertiary sandstones of somewhat uncertain quality are exposed in Sheridan County.

STATISTICS OF PRODUCTION.

The total production of sandstone in the United States during 1914 was valued at a little more than $7,500,000. Table 4, compiled by Loughlin,[a] shows the relative amount of sandstone quarried as compared with other types of stone, and also the values of the different rocks devoted to various uses.

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[a] Loughlin, G. F., The stone industry in 1914: Mineral Resources of U. S. for 1914, U. S. Geol. Survey, 1915, pt. 2, p. 826.

TABLE 4.—*Value of granite, basalt and related rocks (trap rock), sandstone, limestone, and marble sold for various purposes in 1913 and 1914, by kinds and uses.*

1913.

Kind.	Building (rough and dressed).	Monumental (rough and dressed).	Paving.	Curbing.	Flagging.	Rubble.	Riprap.	Crushed.	Other.	Total.
Granite	$6,662,428	$4,715,084	$2,755,995	$814,290	$13,172	$566,343	$1,108,696	$3,851,621	$245,588	$20,733,217
Basalt and related rocks (trap rock)	68,690		204,346			381,069	951,544	7,303,259	225,576	9,134,494
Sandstone	**1,874,299**		**736,767**	**1,154,836**	**553,129**	**200,822**	**813,184**	**1,450,767**	**465,161**	**7,248,965**
Limestone	4,509,339		239,340	108,793	7,337	440,480	1,331,423	19,072,224	13,036,493	38,745,429
Marble [a]	4,982,463	2,497,564							390,863	7,870,890
Total	18,097,219	7,212,648	3,936,448	2,077,919	573,638	1,588,714	4,204,857	31,677,871	14,363,681	83,732,995

1914.

Kind.	Building (rough and dressed).	Monumental (rough and dressed).	Paving.	Curbing.	Flagging.	Rubble.	Riprap.	Crushed.	Other.	Total.
Granite	$6,481,091	$4,744,088	$2,831,568	$760,952	$13,849	$322,371	$715,812	$3,975,575	$183,613	$20,028,919
Basalt and related rocks (trap rock)	45,134		112,246			404,600	1,054,947	6,225,805	23,266	7,865,998
Sandstone	**1,825,179**		**713,692**	**988,317**	**519,957**	**105,906**	**813,460**	**1,898,505**	**636,792**	**7,501,808**
Limestone	3,896,854		114,877	120,407	7,134	423,336	1,123,123	18,061,881	10,146,543	33,894,155
Marble [a]	5,548,294	2,303,484							269,634	8,121,412
Total	17,796,552	7,047,572	3,772,383	1,869,676	540,940	1,256,213	3,707,342	30,161,766	11,259,848	77,412,292
Percentage of decrease (—) in 1914	—1.66	—2.29	—4.17	—10.02	—5.70	—20.93	—11.83	—4.79	—21.61	—7.55

[a] Includes stone used for both exterior and interior building.

The value of sandstones produced in the various States for the years 1910 to 1914 is shown in Table 5.[a]

TABLE 5.—*Value of sandstone (including quartzite and bluestone) produced and sold in the United States, 1910–1914, by States.*

State.	1910	1911	1912	1913	1914
Alabama	$109,063	$73,195	$27,596	$151,111	$161,773
Arizona	131,716	[a] 57,100	21,524	88,391	23,760
Arkansas	71,641	85,529	80,538	89,395	79,358
California	113,438	176,213	70,724	139,486	277,657
Colorado	189,603	135,673	108,169	96,964	97,029
Connecticut	(b)	(a)	(c)	(c)	(c)
Florida	....	(a)	(c)	(c)	....
Georgia	....	....	(c)	(c)	....
Idaho	34,070	40,097	13,883	20,111	22,837
Illinois	5,710	30,953	32,720	28,781	72,738
Indiana	4,141	7,078	(c)	(c)	(c)
Iowa	14,456	56,312	1,551	1,612	1,319
Kansas	25,691	13,774	6,031	1,602	2,274
Kentucky	90,729	97,439	114,650	81,171	60,926
Maryland	18,226	10,097	15,950	16,435	8,128
Massachusetts	[b] 424,485	[a] 406,072	307,838	404,817	428,926
Michigan	31,233	12,985	16,438	19,224	(c)
Minnesota	483,578	292,366	349,063	315,149	210,099
Missouri	39,398	19,748	15,004	10,195	3,588
Montana	59,019	34,437	33,280	51,081	(c)
Nebraska	....	(a)	(c)	(c)	(c)
Nevada	(b)	....	....	....	....
New Jersey	112,650	155,765	166,583	69,584	53,394
New Mexico	1,402	4,085	(c)	66,700	412,845
New York	[d] 1,810,770	[d] 2,353,995	[d] 1,651,317	[d] 1,568,952	[d] 1,475,231
North Carolina	(b)	[a] 10,385	(c)	(c)	(c)
Ohio	1,402,131	1,334,947	1,312,300	1,316,028	1,523,796
Oklahoma	19,801	90,971	5,334	1,010	1,934
Oregon	[b] 30,375	[a] 1,668	....	(c)	(c)
Pennsylvania	[d] 1,595,070	[d] 1,333,309	[d] 1,367,601	[d] 1,359,533	[d] 1,140,182
South Dakota	156,576	141,615	139,167	163,165	126,413
Tennessee	(b)	(a)	(c)	(c)	(c)
Texas	40,471	28,000	82,501	58,750	197,800
Utah	43,589	41,953	32,562	23,965	67,578
Virginia	25,080	31,315	4,020	(c)	150,469
Washington	438,581	301,843	344,476	560,468	450,436
West Virginia	[b] 212,308	203,935	183,410	146,698	142,459
Wisconsin	189,654	144,430	179,352	213,229	167,595
Wyoming	5,314	3,584	3,730	(c)	11,831
Other States	....	....	206,299	185,358	129,433
Total	7,930,019	7,730,868	6,893,611	7,248,965	7,501,808

[a] Arizona includes Florida; Massachusetts includes Connecticut; Oregon includes Nebraska; North Carolina includes Tennessee.
[b] Massachusetts includes Connecticut; Oregon includes Nevada; West Virginia includes Tennessee and North Carolina.
[c] Included in "Other States."
[d] Includes bluestone.

The value of sandstone produced by the various States in 1914, and classified by uses, is given in Table 6.[b]

[a] See Loughlin, G. F., Op. cit., p. 883. [b] See Loughlin, G. F., Op. cit., p. 886.

TABLE 6.—*Value of the marketed production of sandstone (including quartzite and bluestone) in the United States in 1914, by States and uses.*

State.	Rough building.	Dressed building.	Ganister.	Paving.	Curbing.	Flagging.	Rubble.
Alabama	$57,079		$2,300				$1,558
Arizona	10,050						10
Arkansas	375	$177			$3,539	$203	250
California	2,502	21,414					502
Colorado	[illegible]	13,428	8,267	$38,487	4,762	2,357	3,795
Idaho	16,291	6,330					125
Illinois	525		1,5[illegible]3				
Iowa	453						80
Kansas	[illegible]	241			50	349	674
Kentucky	3,277	55,407					
Maryland	1,000		2,008				2,720
Massachusetts	62,973	17,894					920
Minnesota	3,221	59,522		100,671	8,340		4,738
Missouri	695	1,[illegible]4					600
New Jersey	29,794	200		325	275	300	
New Mexico	[illegible]	137					1,200
New York	53,461	176,116		361,850	375,601	112,014	1,989
Ohio	113,193	452,198	725	19,175	[illegible]	354,475	19,522
Oklahoma	326						
Pennsylvania	222,122	[illegible]	239,211	44,1[illegible]5	113,147	48,963	44,[illegible]9
South Dakota	10,153	15,379		24,[illegible]			545
Texas				8,000	2,000		3,000
Utah	2,709			[illegible]		1,240	1,043
Virginia							135
Washington	2,372	15,674		13,213			263
West Virginia	9,315	66,147		6,000	1,854	11	5,700
Wisconsin	19,891	35,451	34,170	37,000			6,861
Wyoming	272						
Other States [a]	67,007	13,078			175	45	4,987
Total	[illegible]	1,12[illegible]	28[illegible],244	71[illegible],[illegible]92	988,317	519,957	105,906

State.	Riprap.	Road metal.	Railroad ballast.	Concrete.	Other.	Total value.
Alabama	$15,694			$85,142		$161,773
Arizona		$4,[illegible]		[illegible]	$[illegible],100	23,760
Arkansas	35,077	5,[illegible]2	$1[illegible]	16,331		79,358
California	22,408	154,[illegible]	7,945	66,672	1,618	27[illegible]
Colorado	[illegible]	1,500	700	2,500	3,602	97,029
Connecticut						(b)
Idaho					91	22,837
Illinois		[illegible]	5,615		9	72,738
Indiana						(b)
Iowa	[illegible]				[illegible]	1,319
Kansas						2,274
Kentucky	2,242					60,926
Maryland		2,400				8,128
Massachusetts		104,625	3	242,511		428,926
Michigan						(b)
Minnesota	1[illegible]			23,804	10,275	210,099
Missouri	16				313	3,588
Montana						(b)
Nebraska						(b)
New Jersey	950	16,500		4,250	[illegible]	53,394
New Mexico	1,800			315,000	94,[illegible]	412,845
New York	6,227	[illegible]	2,659	111,597	209,218	1,475,231
North Carolina						(b)
Ohio	[illegible],155	1,[illegible]75	1,000	3,[illegible]	15	1,[illegible]
Oklahoma				1,600	[illegible]	1,934
Oregon						(b)
Pennsylvania	9,131	93,595	[illegible]	86,526	6,881	1,140,182
South Dakota	13,432	2,500		[illegible],724		126,413
Tennessee						(b)
Texas	149,500	2,000	[illegible]	32,500		197,800
Utah					1,[illegible]	67,578
Virginia	200	[illegible]	9,422	4,062	150	15[illegible]
Washington	41[illegible]					450,436
West Virginia	[illegible]	[illegible]	14,418	14,[illegible]7	50	142,459
Wisconsin	2,181	21,700		10,300	11	167,595
Wyoming	919			10,640		11,831
Other States [a]	24,952		1,672	8,100	9,417	129,433
Total	813,460	681,453	11[illegible]	1,098,985	34[illegible]	7,501,506

[a] Includes Connecticut, Indiana, Michigan, Montana, Nebraska, North Carolina, Oregon, and Tennessee.
[b] Included in "Other States."

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